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Levine

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(54) **FLEXIBLE MEDICAL DEVICE WITH MARKER BAND AND SENSOR**

(2013.01); *A61M 25/09* (2013.01); *A61B 5/02007* (2013.01); *A61B 5/14539* (2013.01); *A61B 5/14542* (2013.01);

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(Continued)

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(58) **Field of Classification Search**

CPC *A61B 5/02007*; *A61B 5/14503*; *A61B 5/14539*; *A61B 5/1459*; *A61B 5/1473*; *A61B 5/6852*; *A61B 5/14865*; *A61M 25/0108*

(73) Assignee: **Makaha Medical, LLC**, Pottstown, PA (US)

See application file for complete search history.

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 1181 days.

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(65) **Prior Publication Data**

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(Continued)

Related U.S. Application Data

(60) Provisional application No. 62/313,711, filed on Mar. 26, 2016.

(51) **Int. Cl.**

A61B 5/145 (2006.01)

A61B 8/12 (2006.01)

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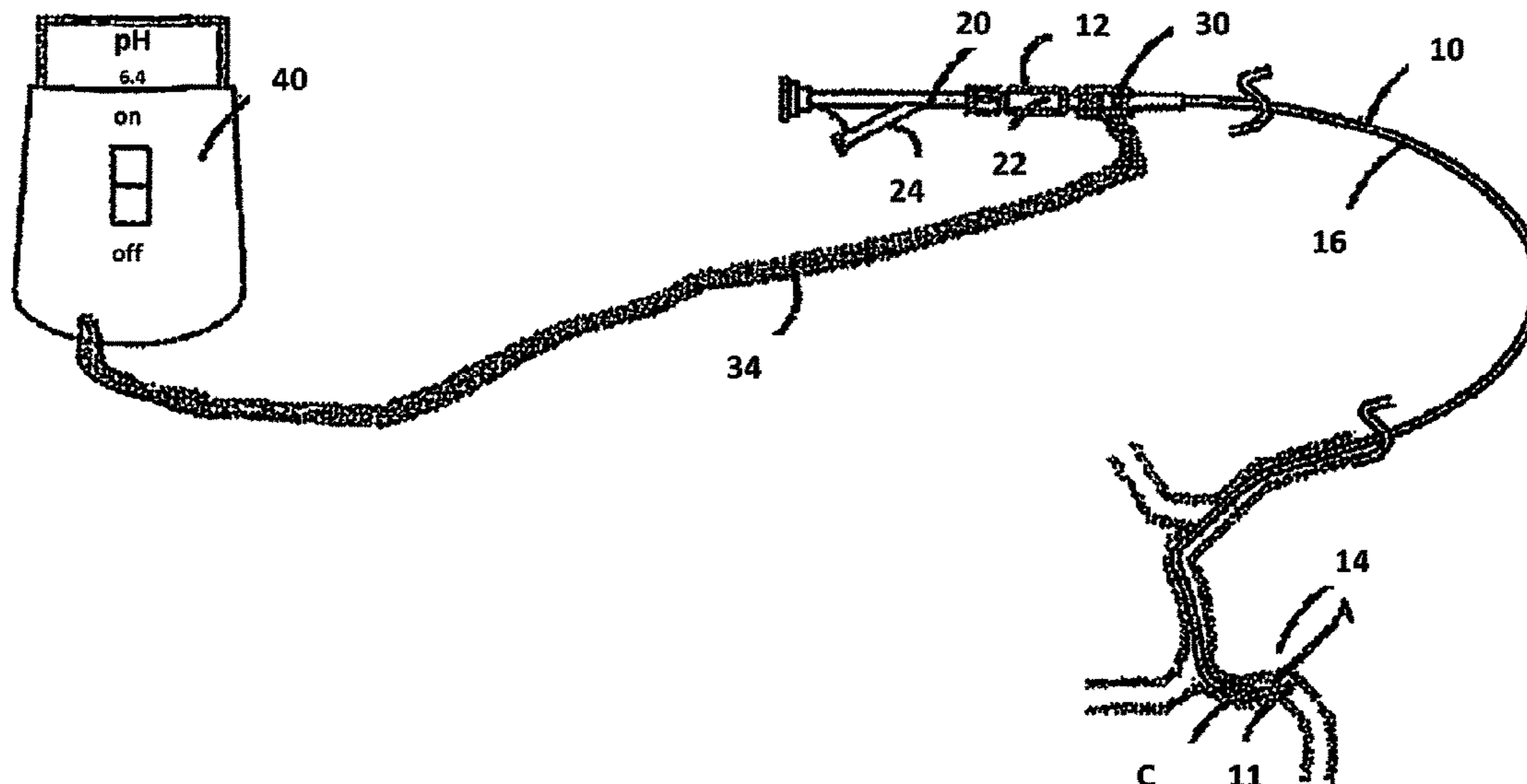
(52) **U.S. Cl.**

CPC *A61B 5/6852* (2013.01); *A61B 5/065* (2013.01); *A61B 5/1473* (2013.01); *A61B 5/14503* (2013.01); *A61B 5/14539* (2013.01); *A61B 5/6851* (2013.01); *A61B 5/742* (2013.01); *A61B 8/085* (2013.01); *A61B 8/0833* (2013.01); *A61B 8/0891* (2013.01); *A61B 8/12* (2013.01); *A61B 8/445* (2013.01); *A61B 8/5223* (2013.01); *A61M 25/0108*

(57) **ABSTRACT**

A system and method for determining a pH level of blood in a vessel of a patient including a flexible elongated device configured and dimensioned for insertion in the vessel of the patient. The elongated device has a tubular portion, a marker band positioned distally of the tubular portion and a pH sensor positioned within the marker band to measure the pH level of blood downstream of the blood clot and an indicator to indicate the measured pH.

20 Claims, 38 Drawing Sheets



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(52) **U.S. Cl.**
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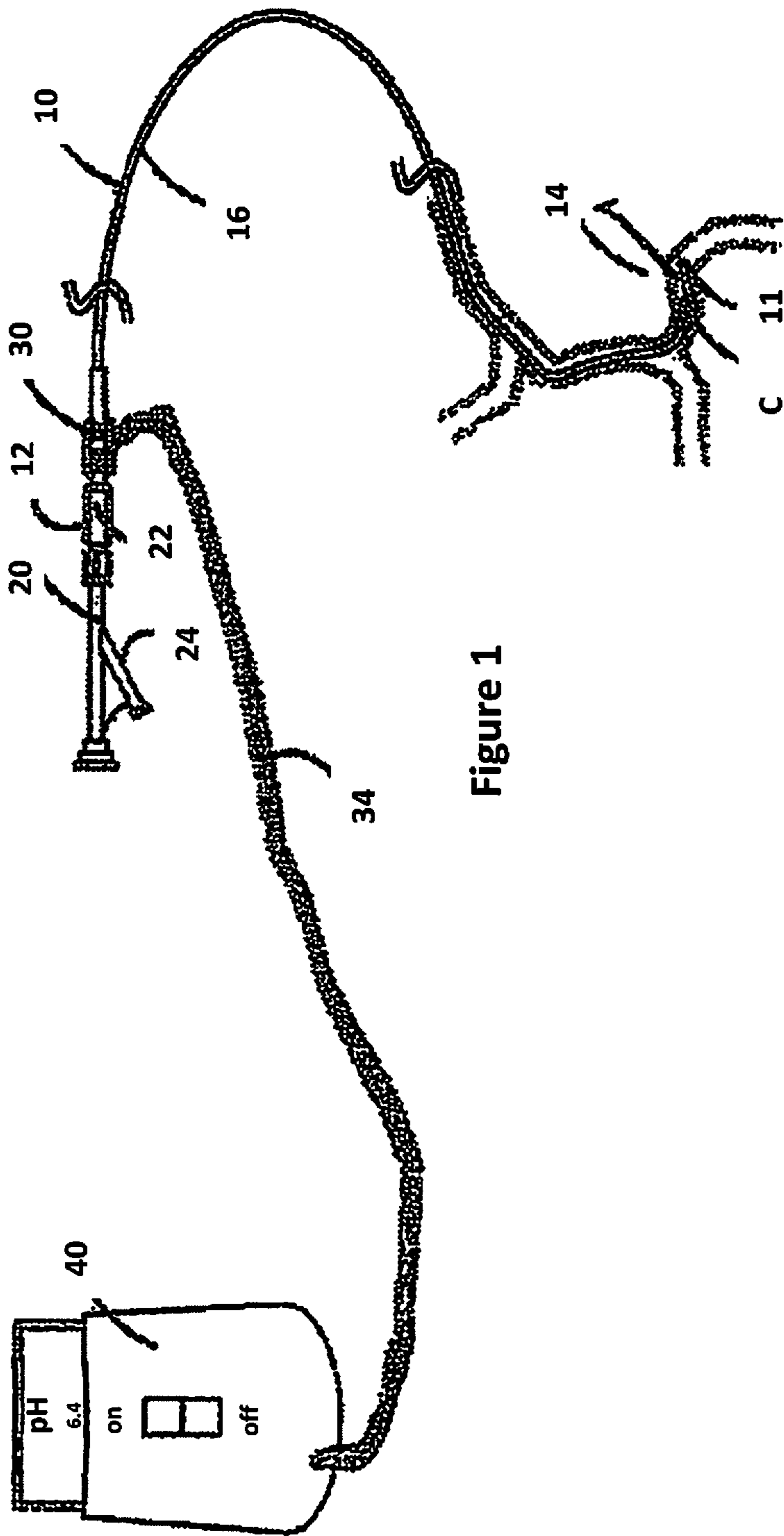


Figure 1

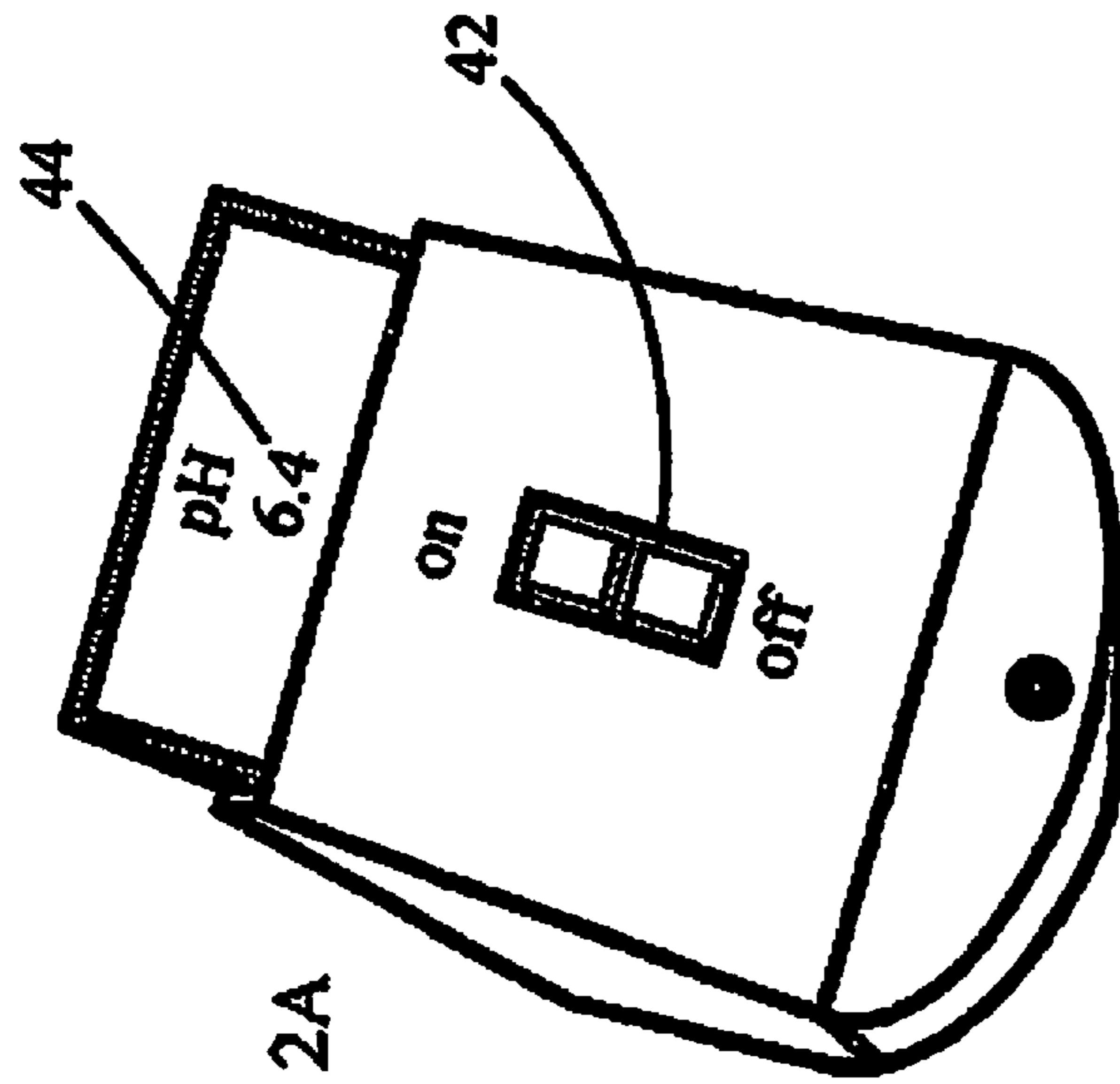


Figure 2A

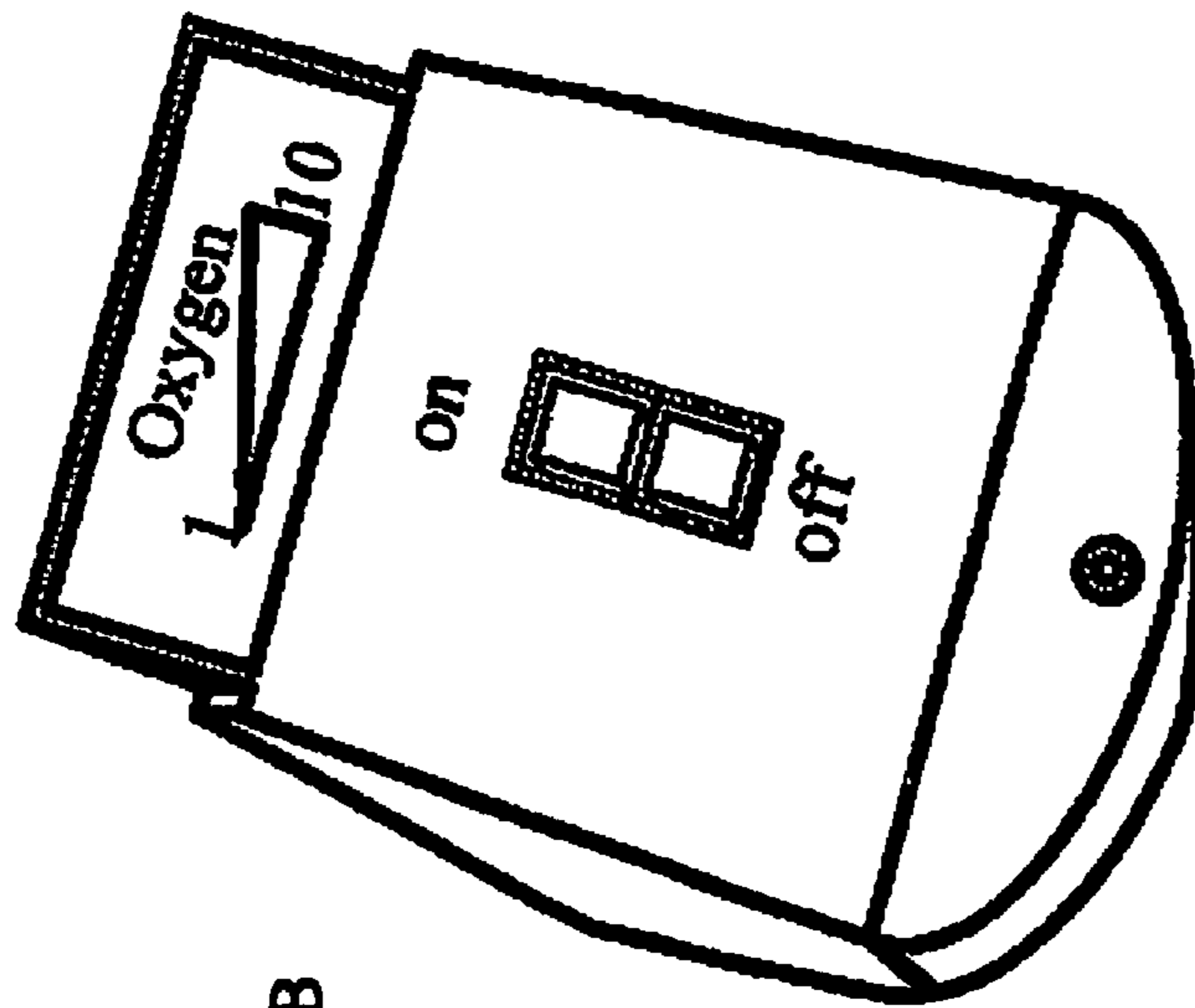


Figure 2B

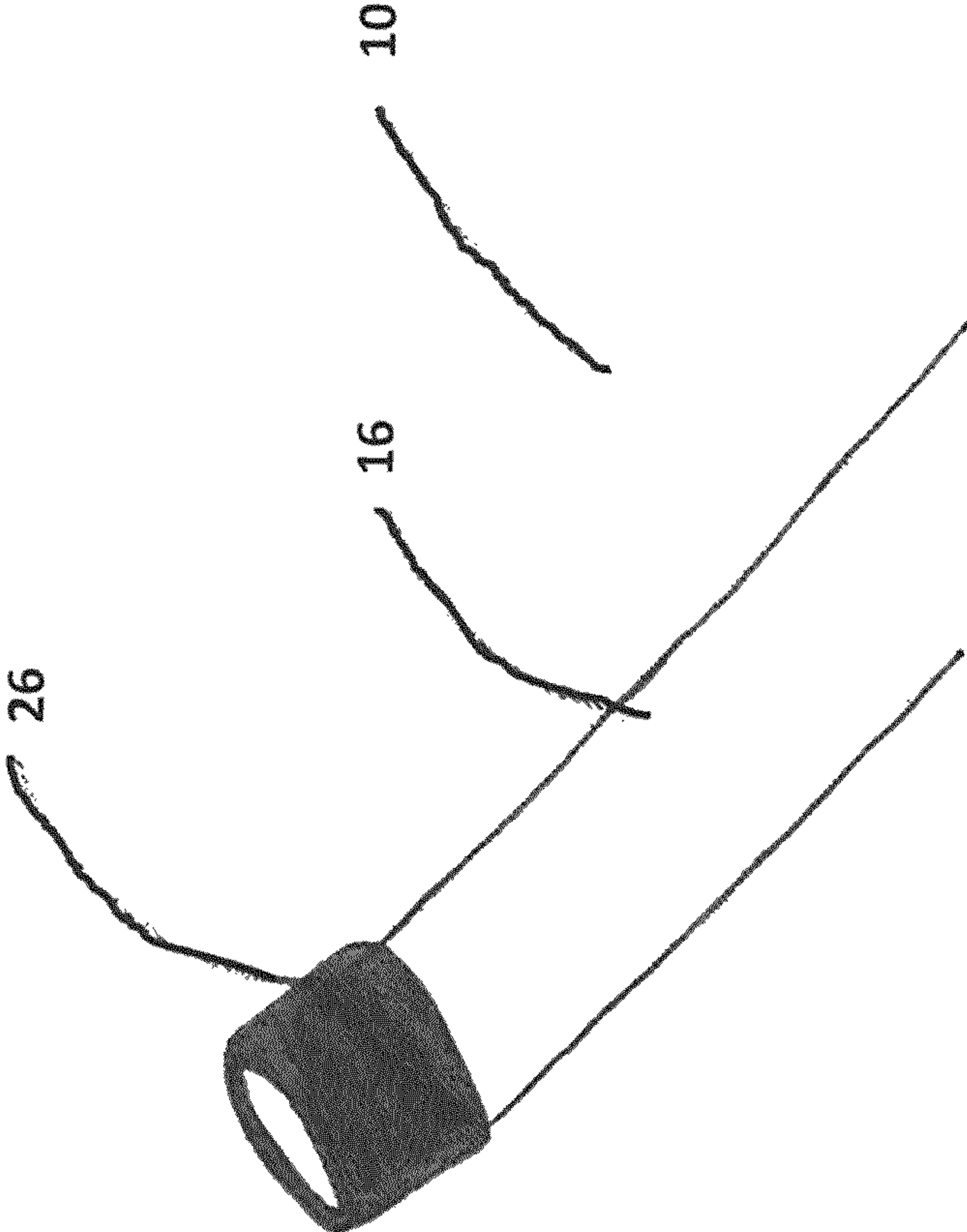


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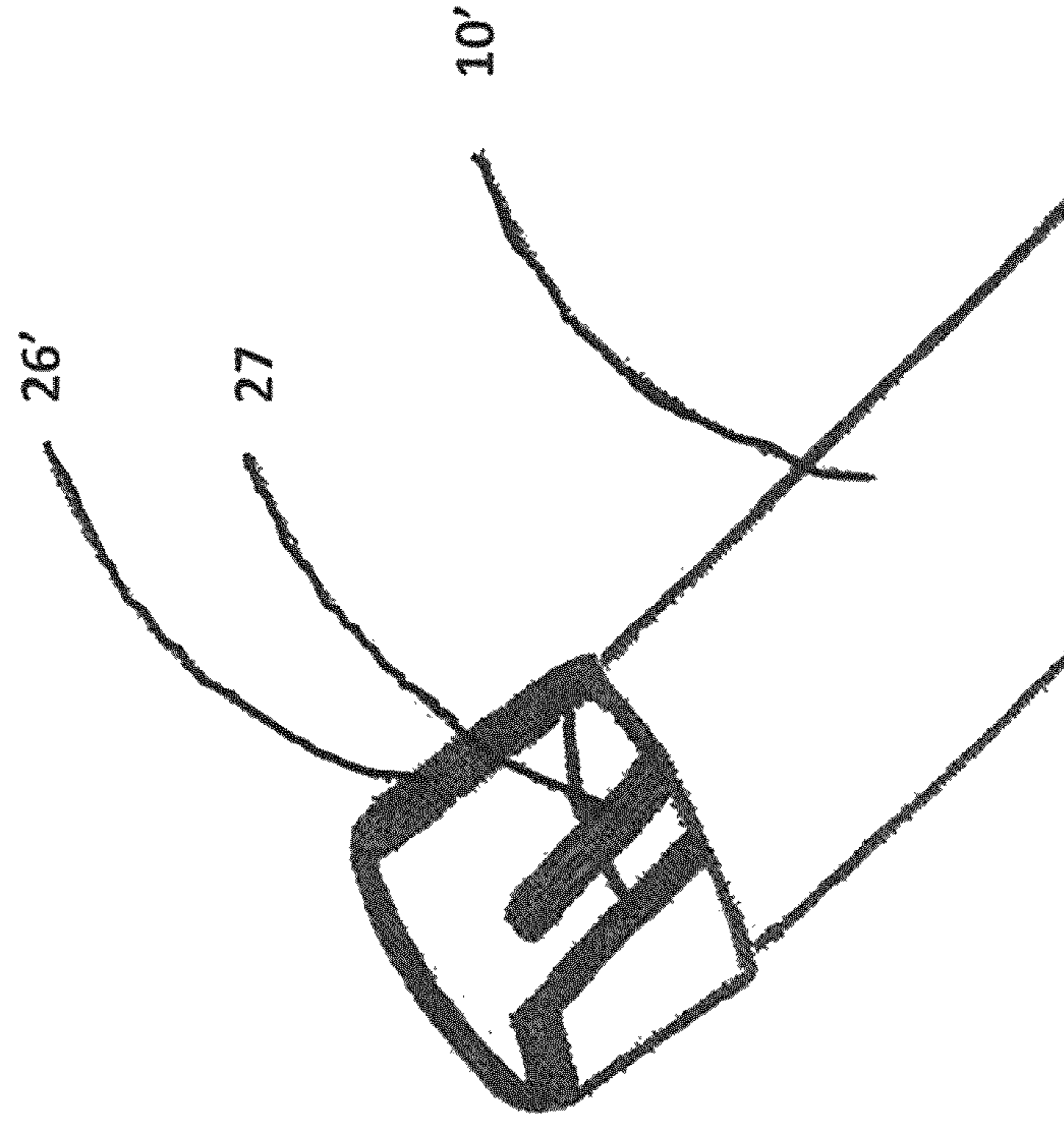


Figure 3B

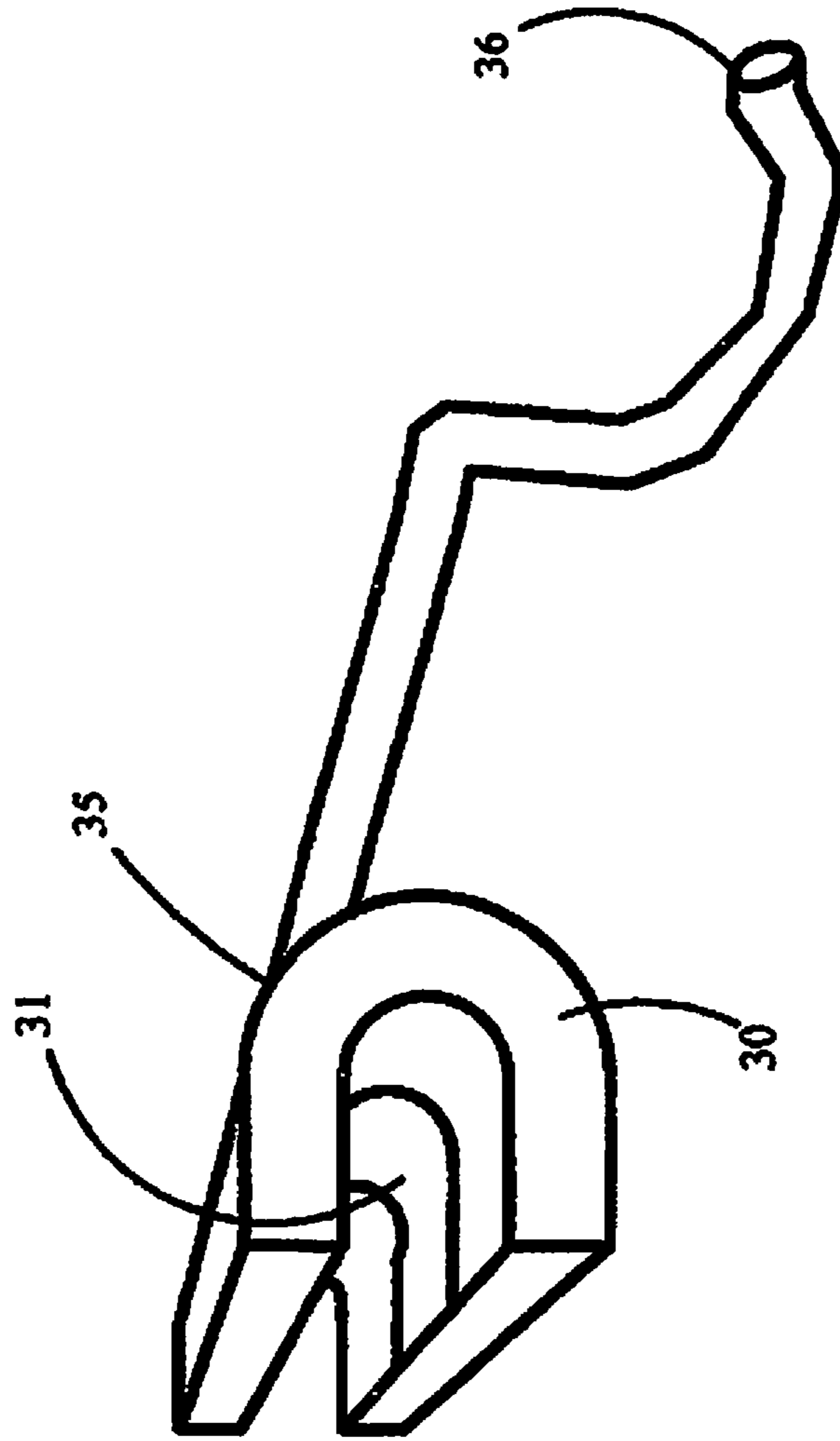


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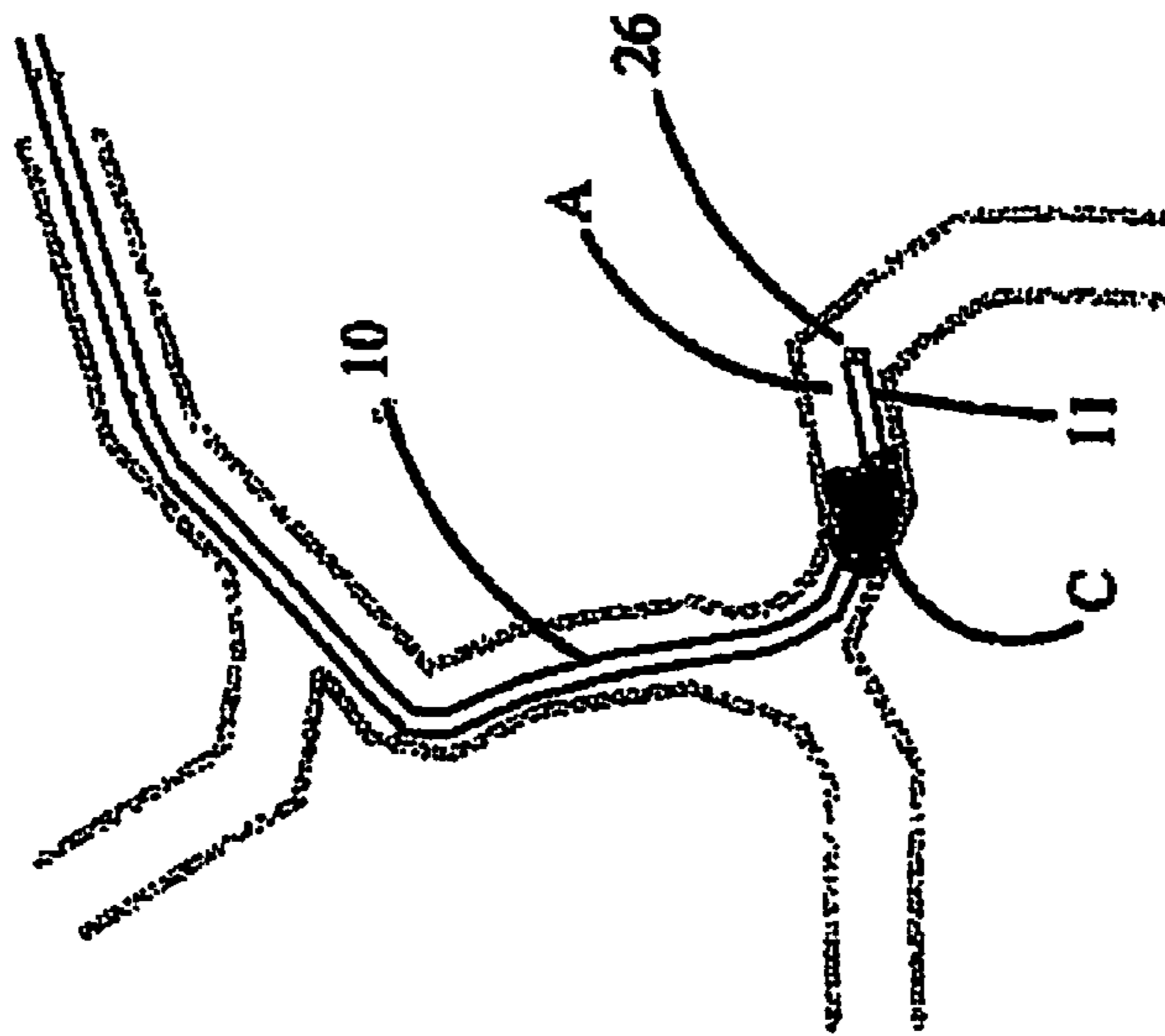


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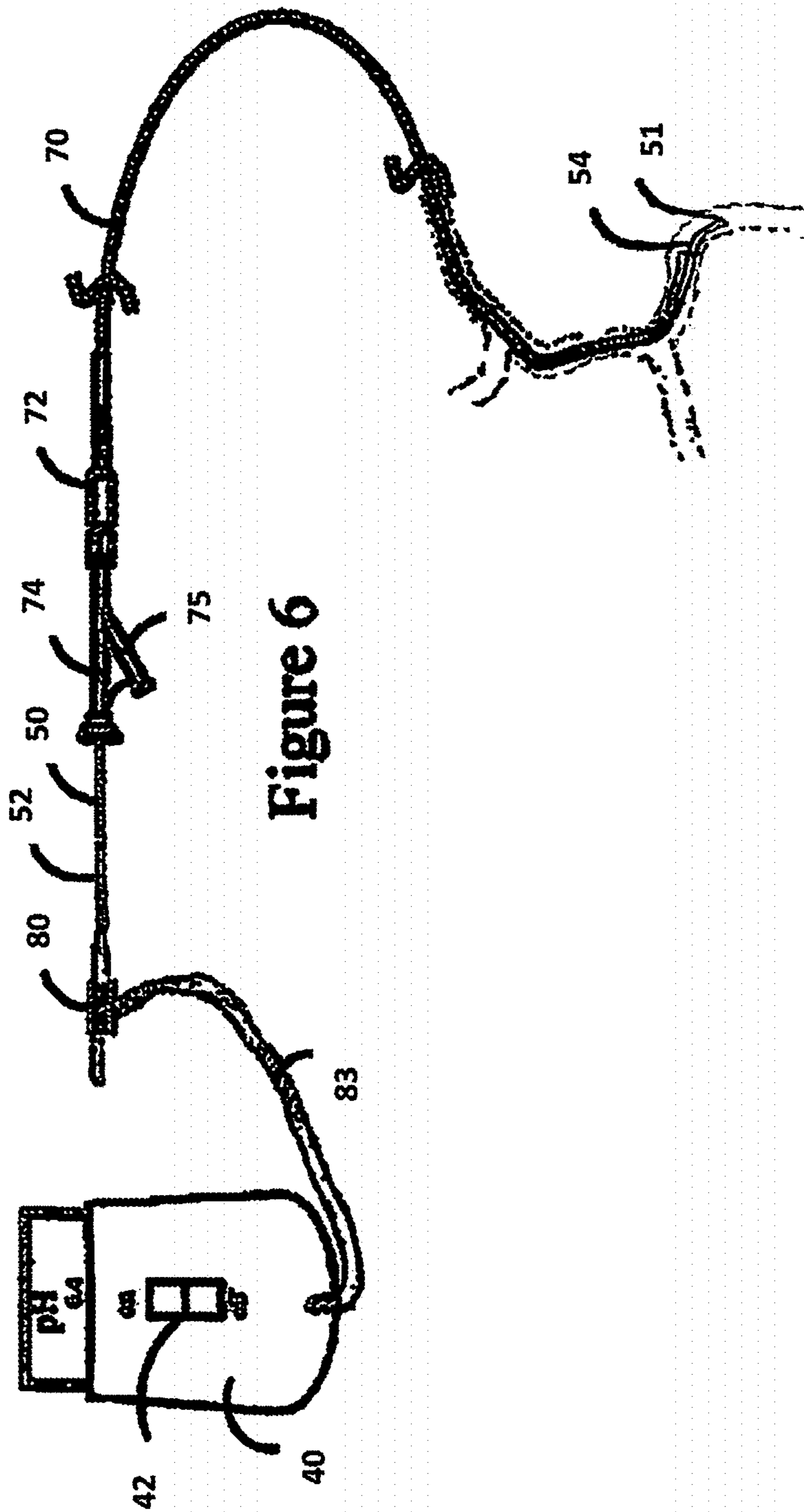


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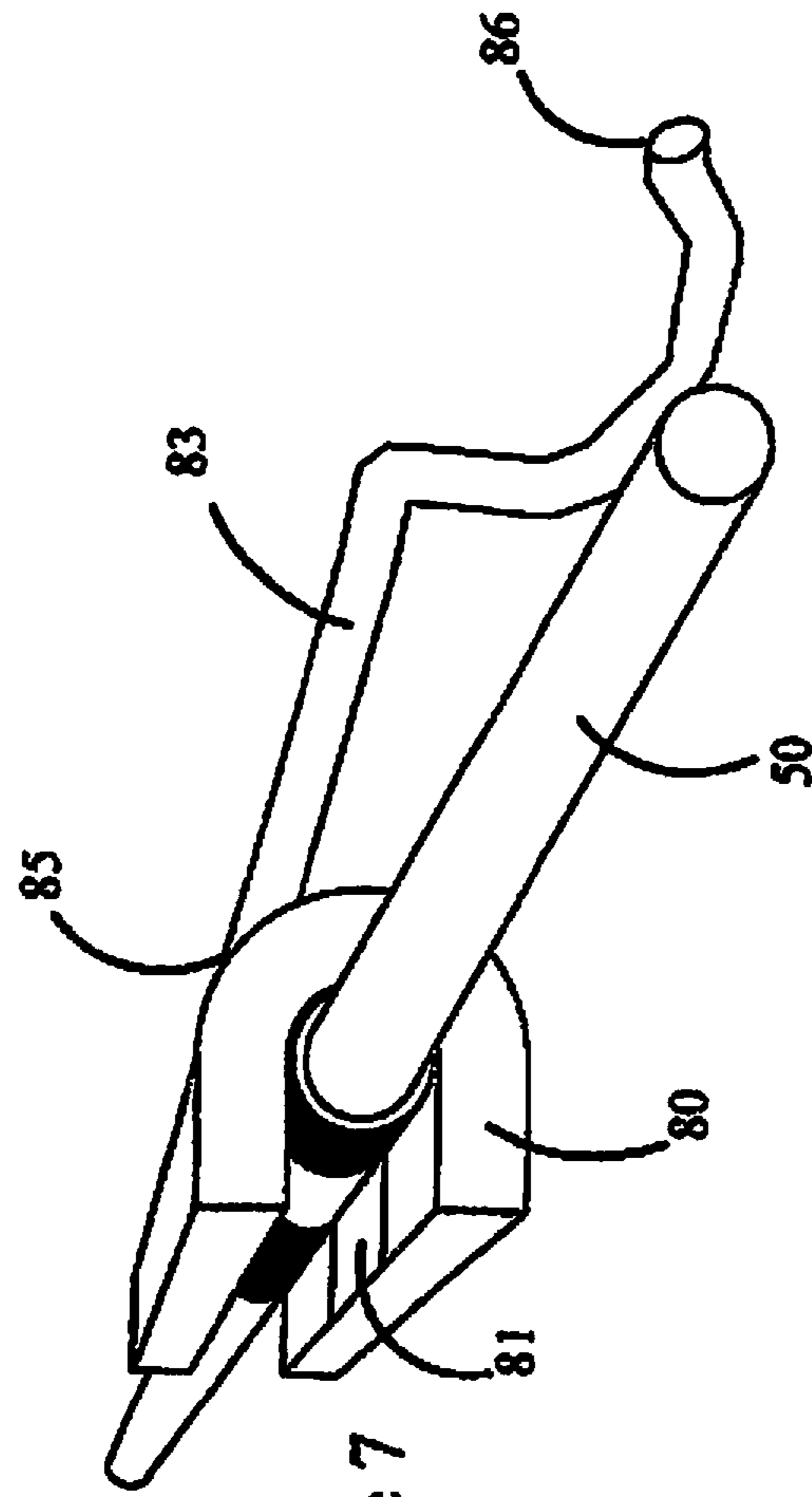
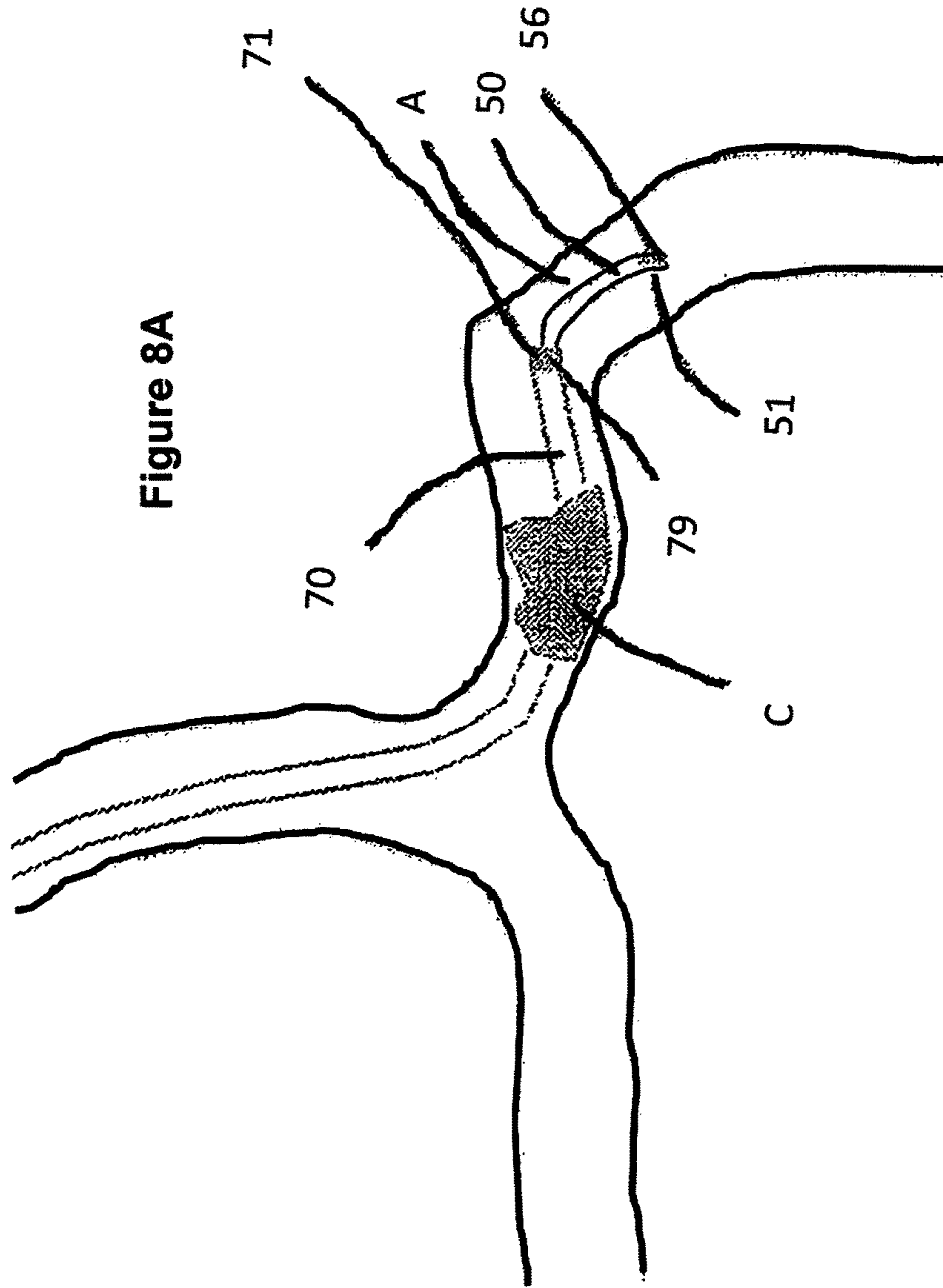


Figure 7



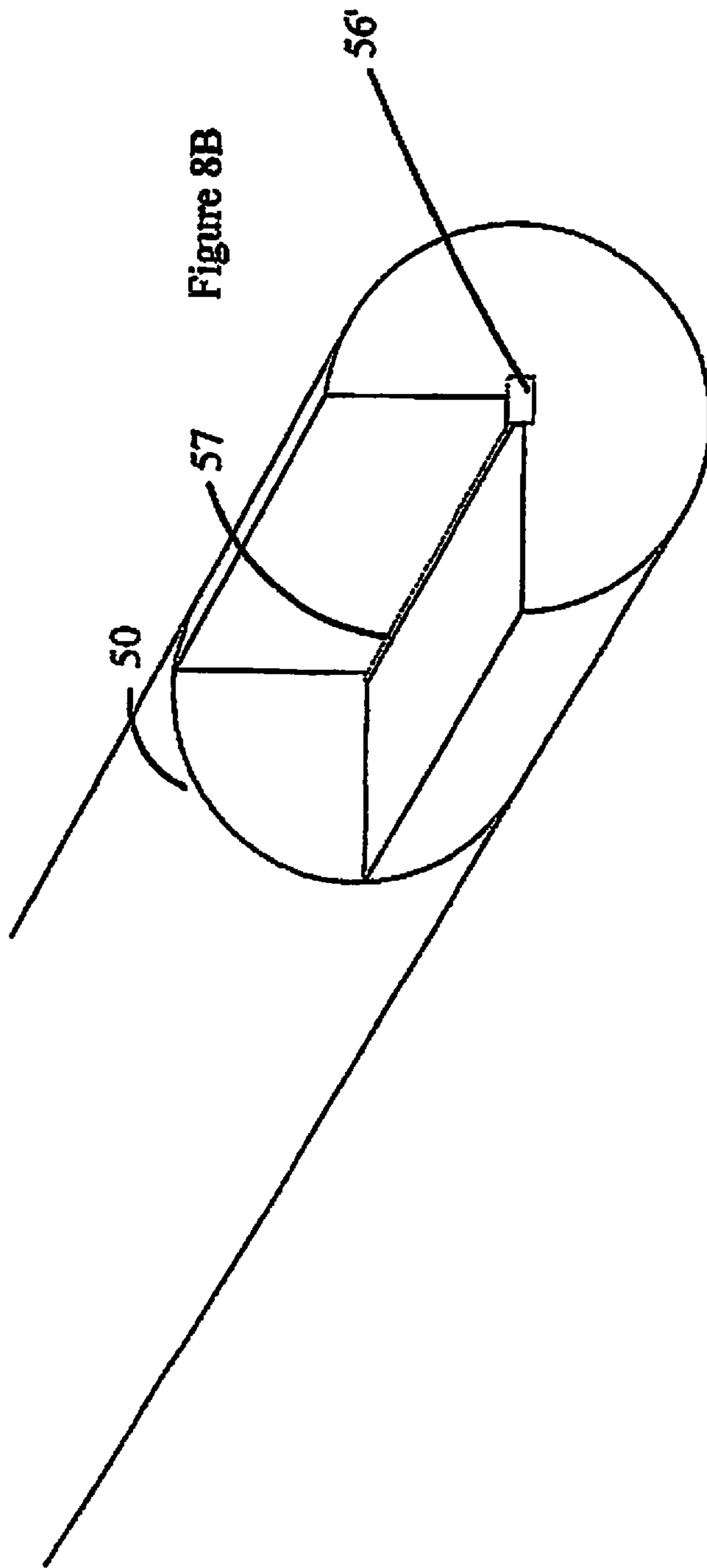
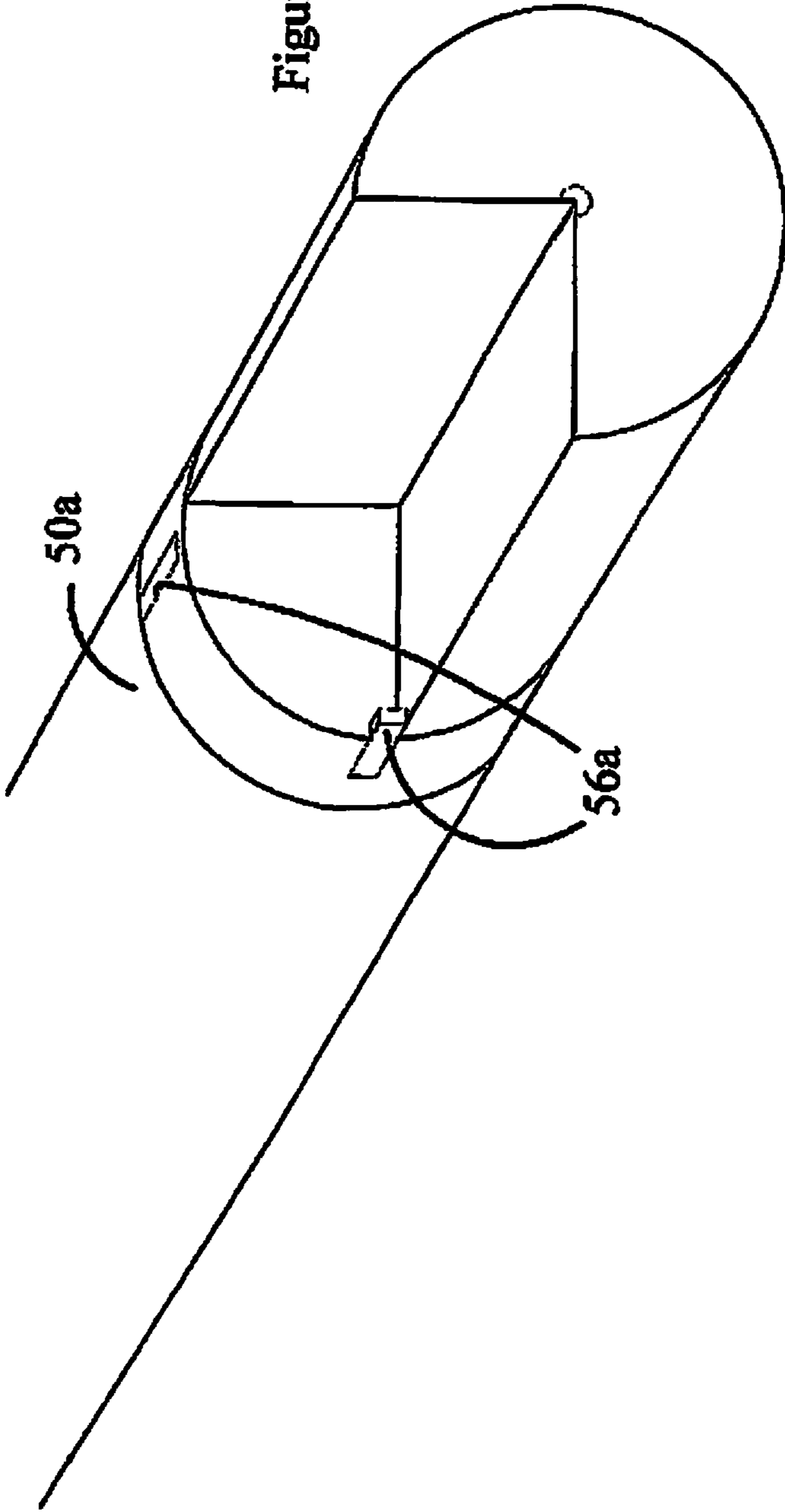


Figure 8C



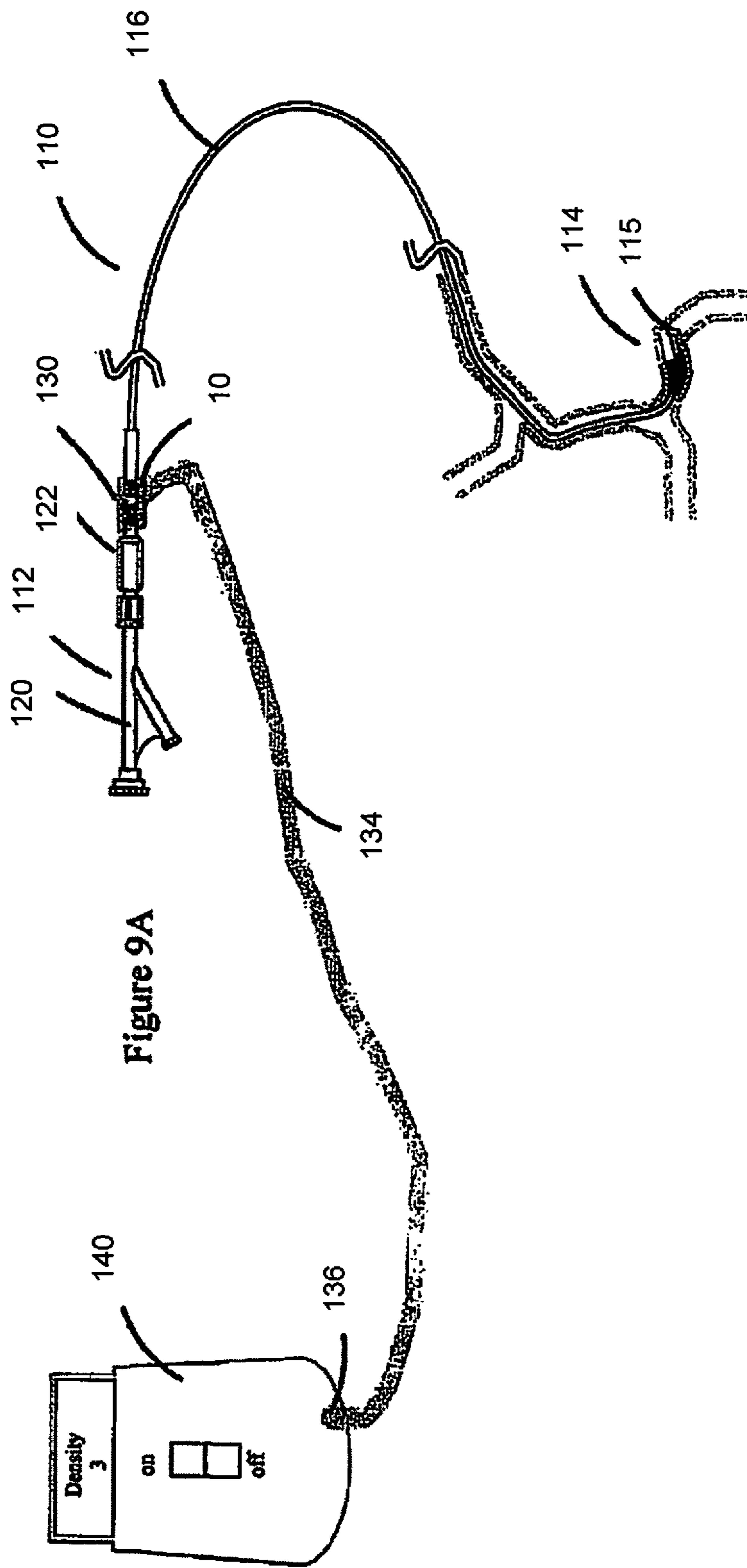
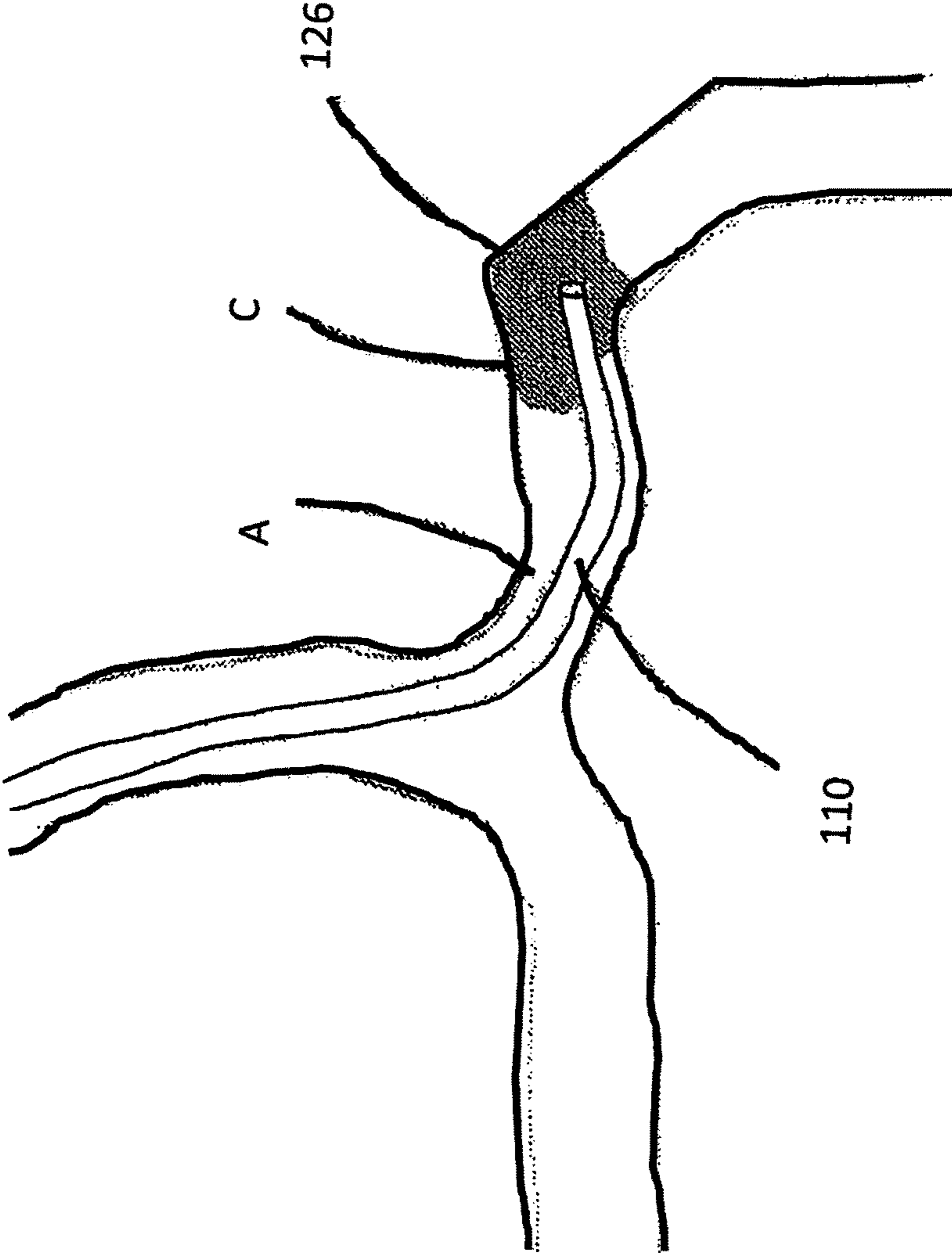


Figure 9B



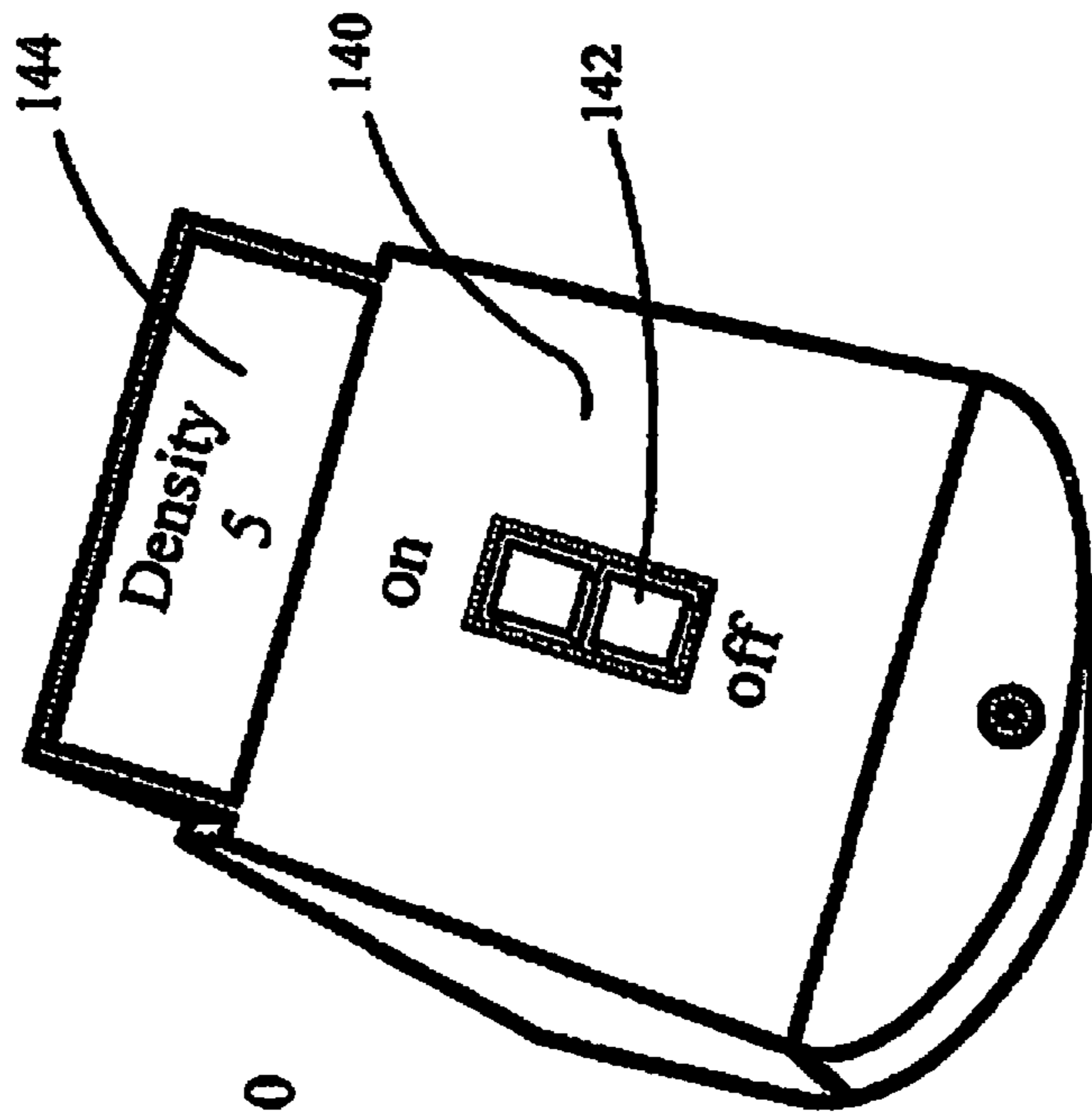


Figure 10

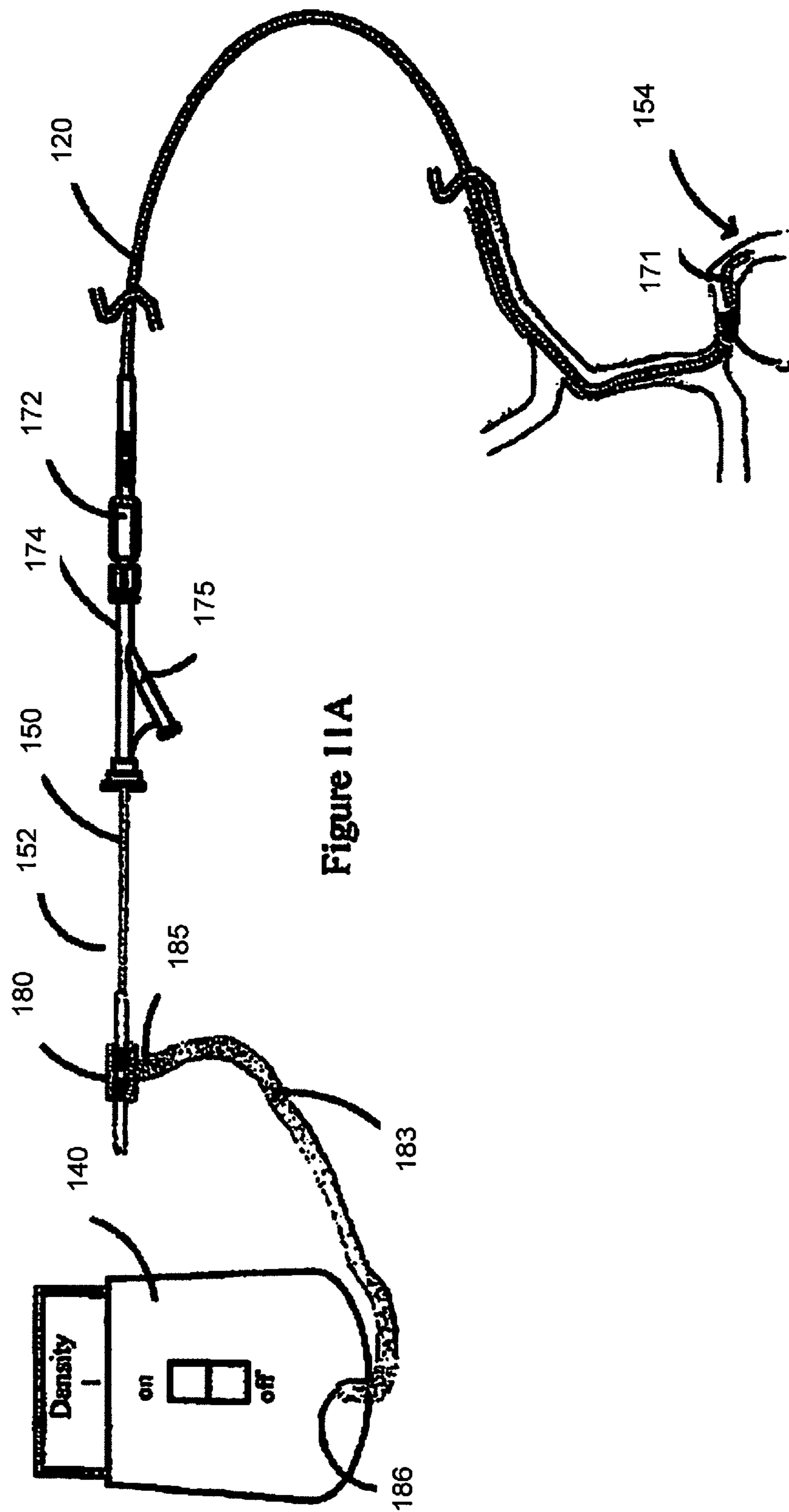


Figure 11A

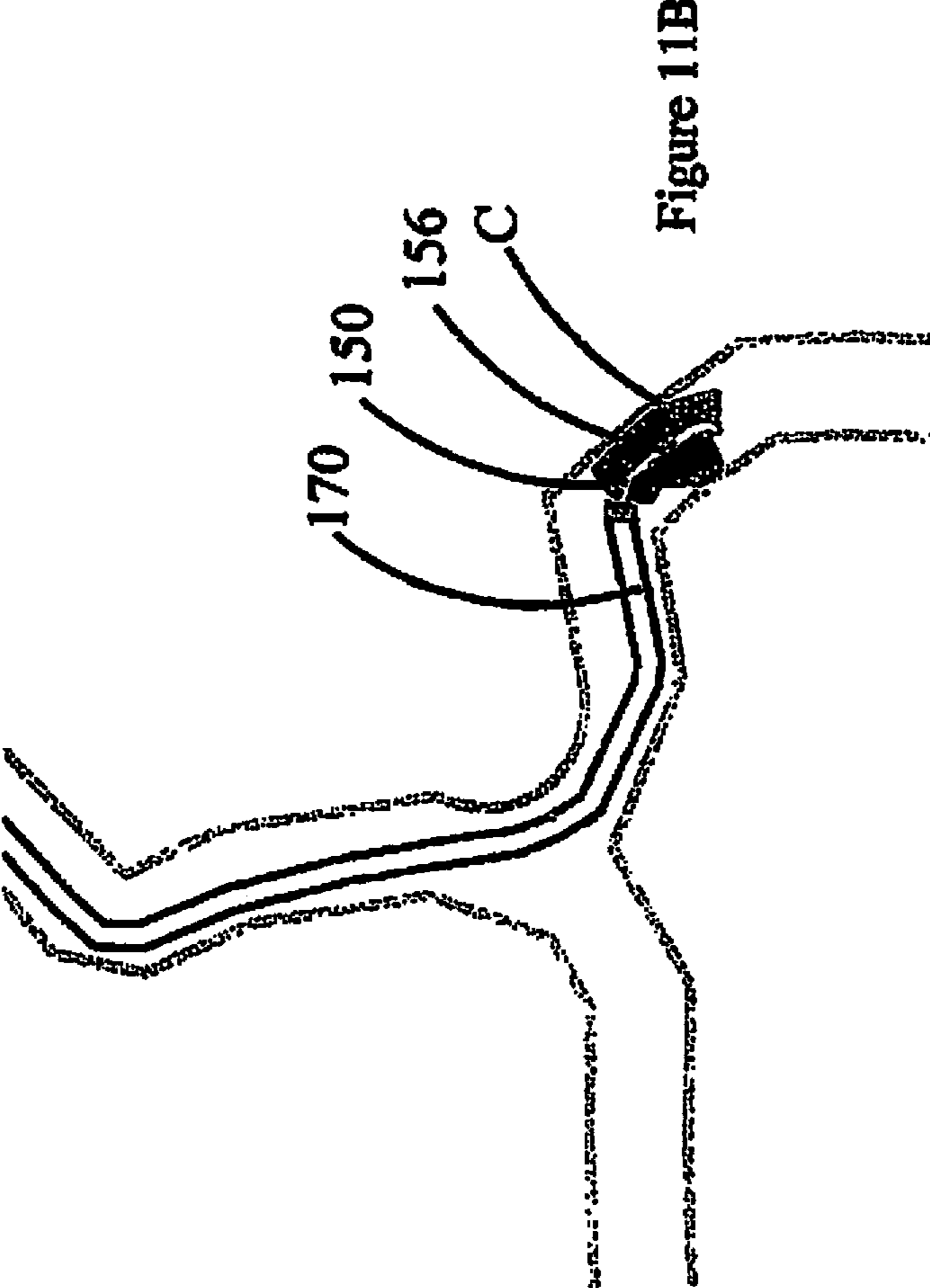


Figure 11B

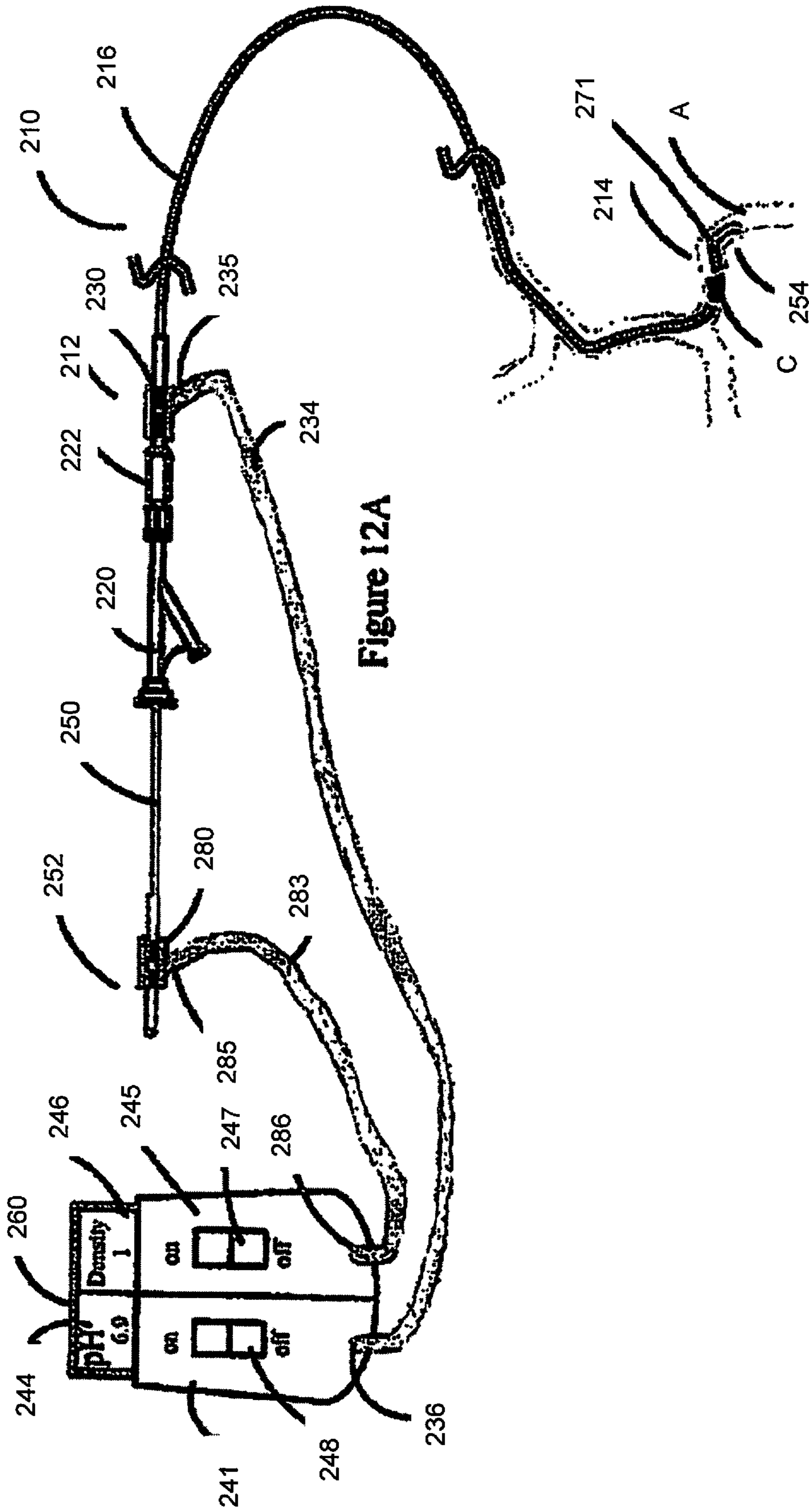
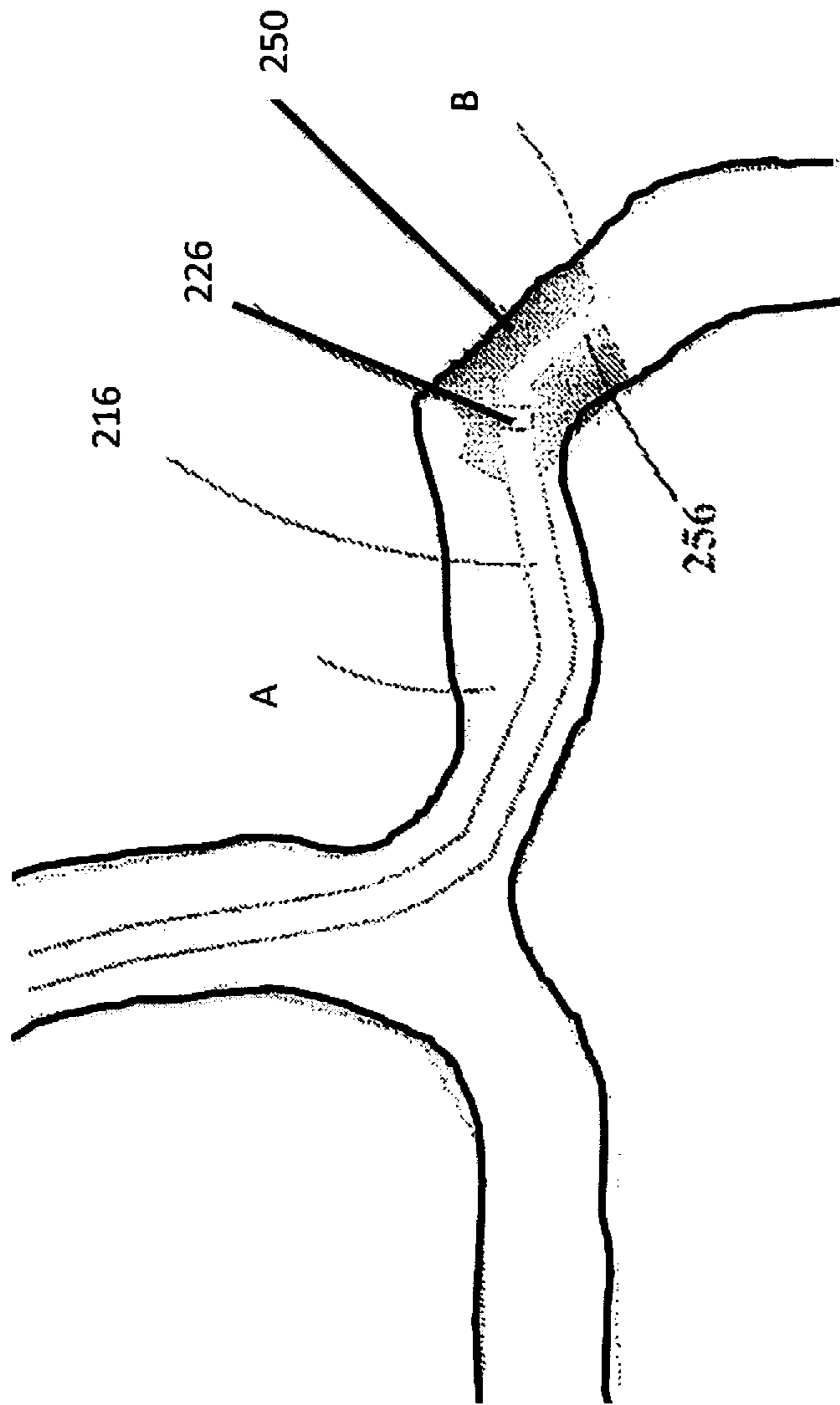


Figure 12B



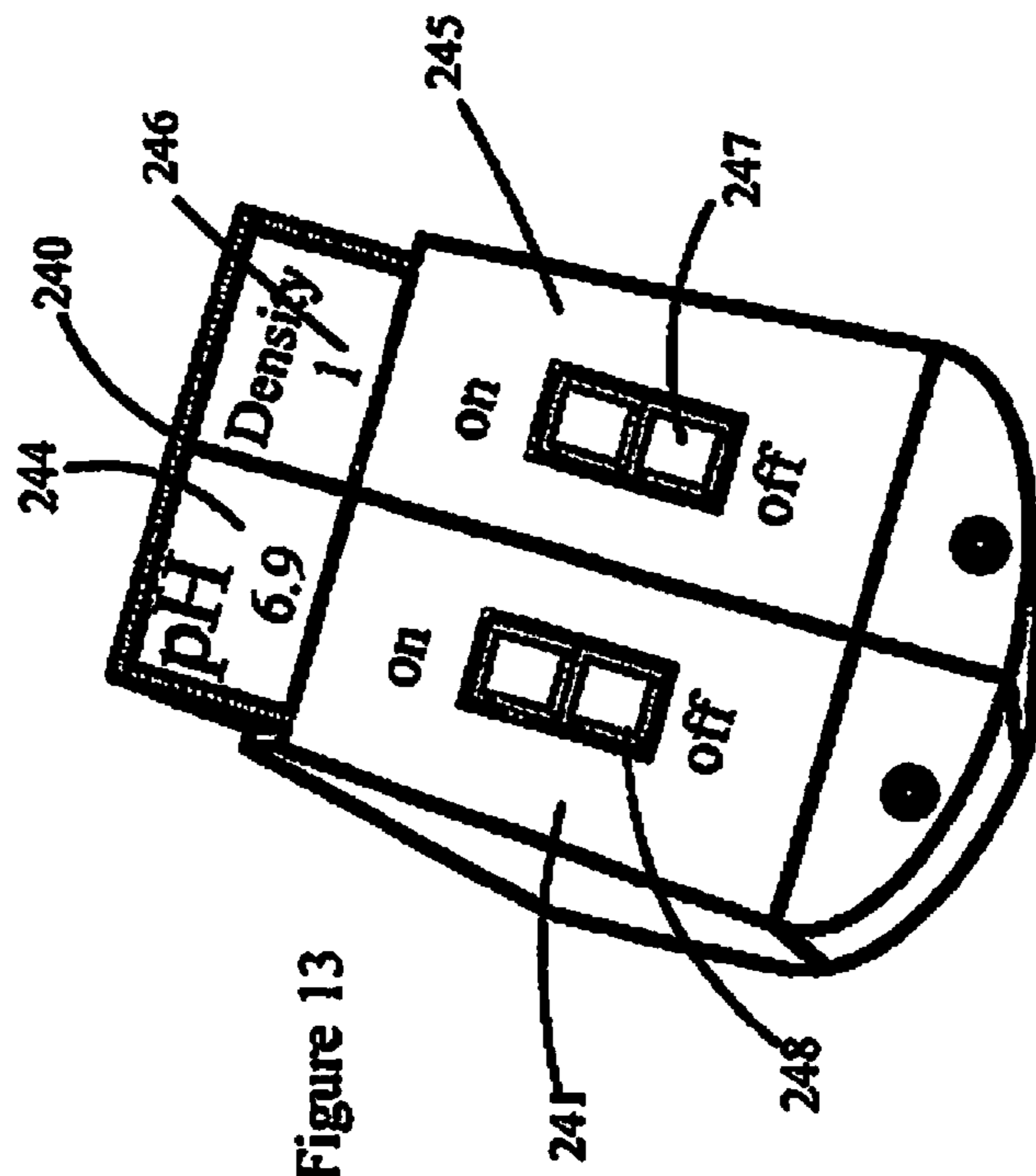


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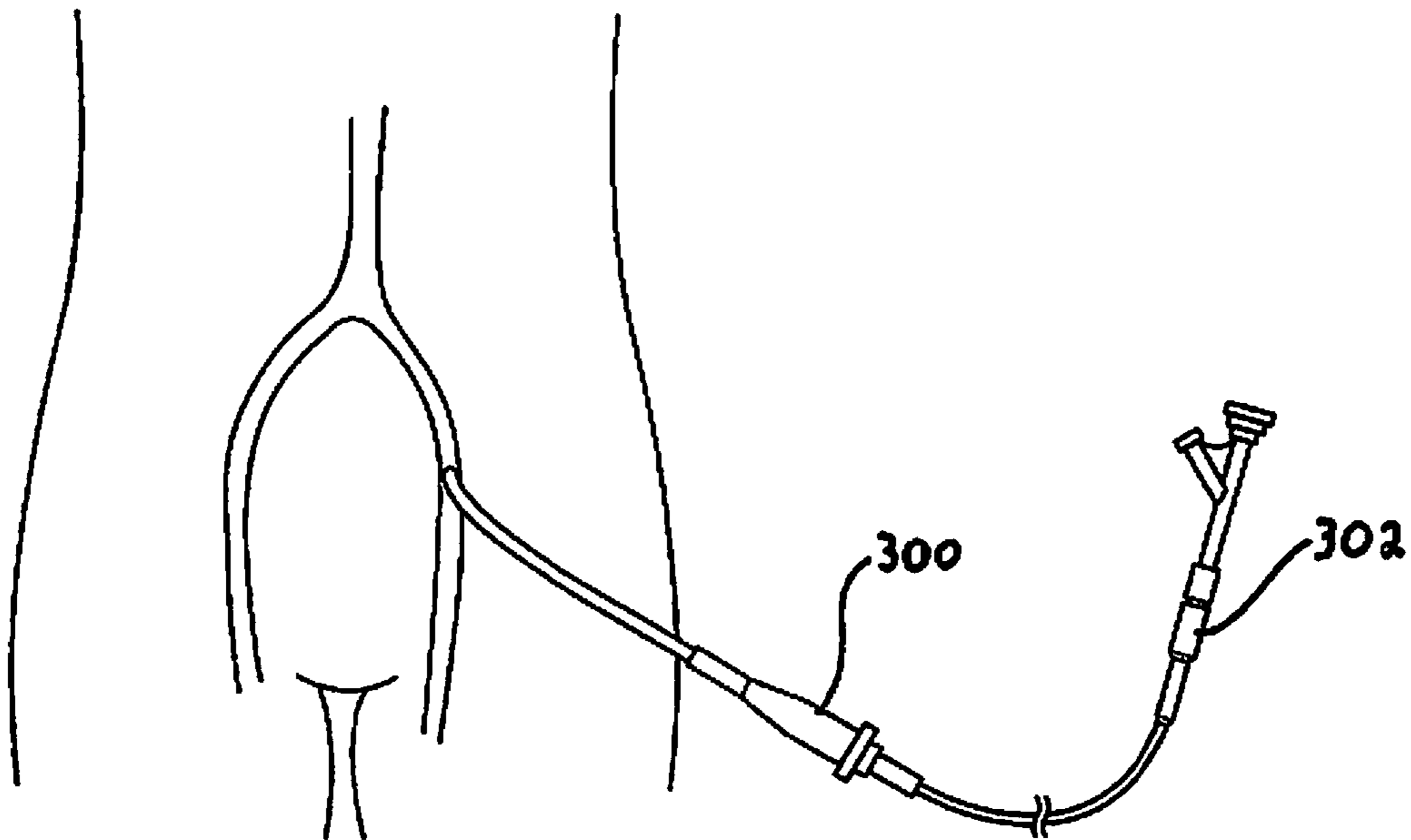
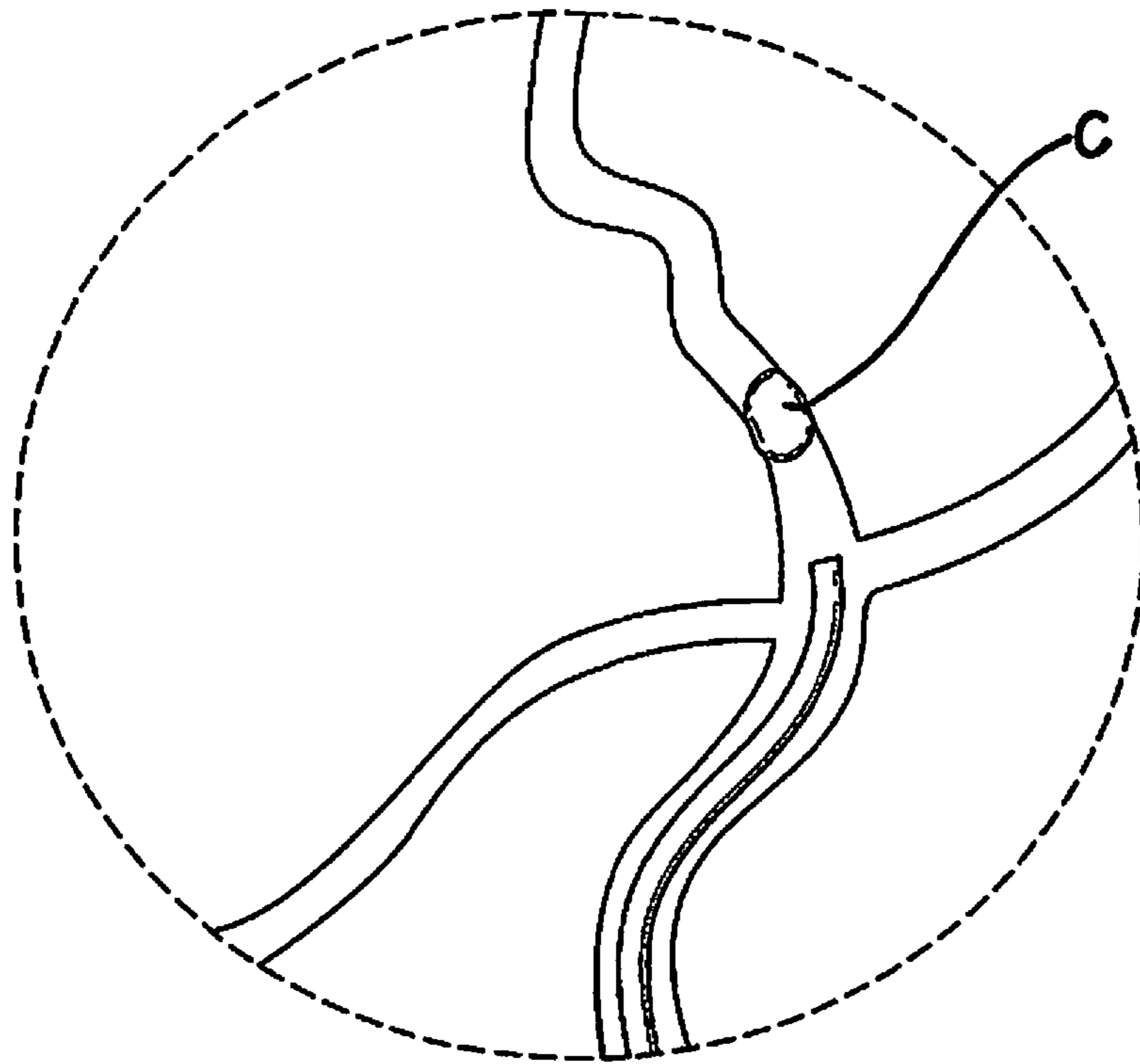


FIG. 14A

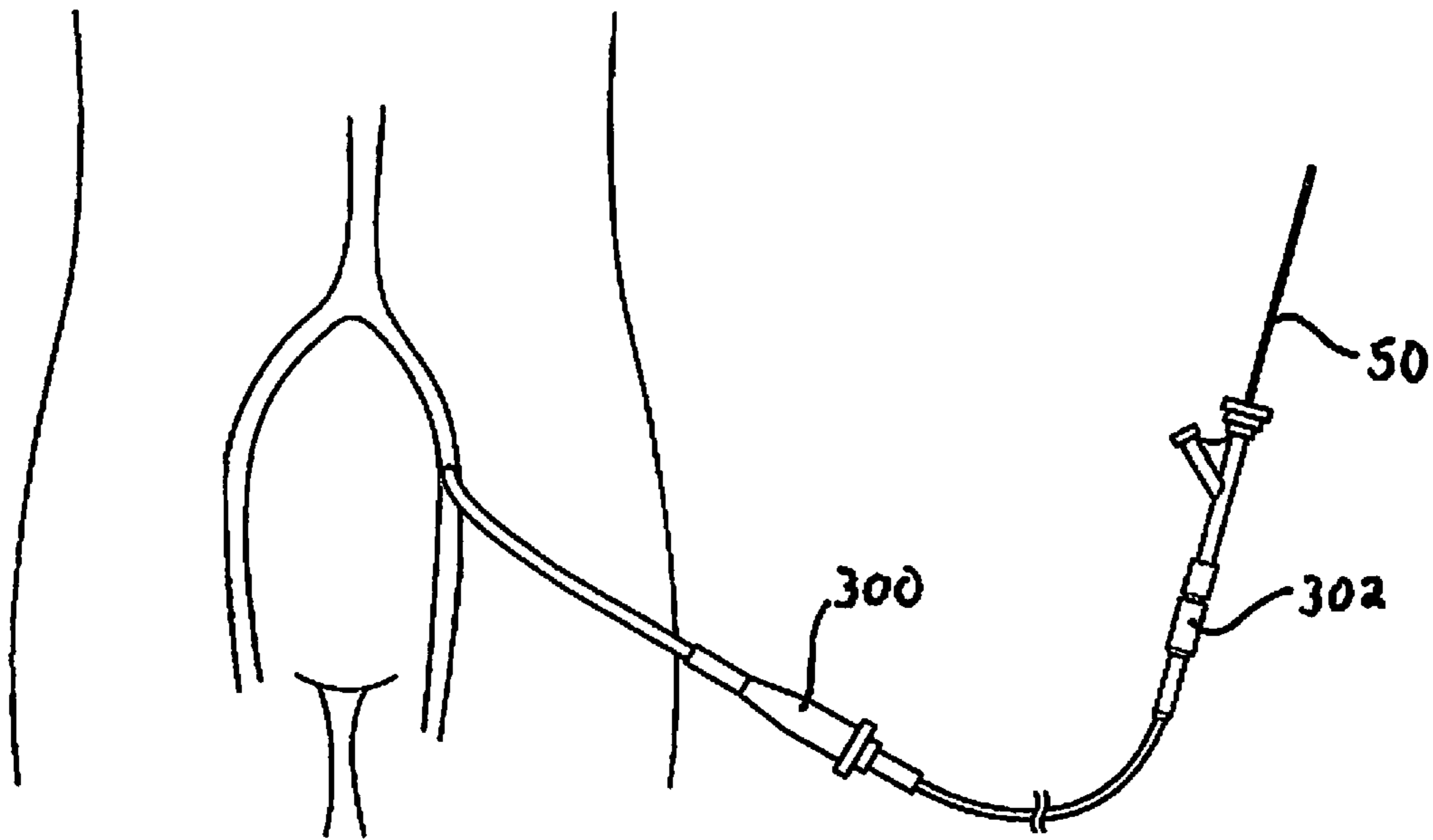
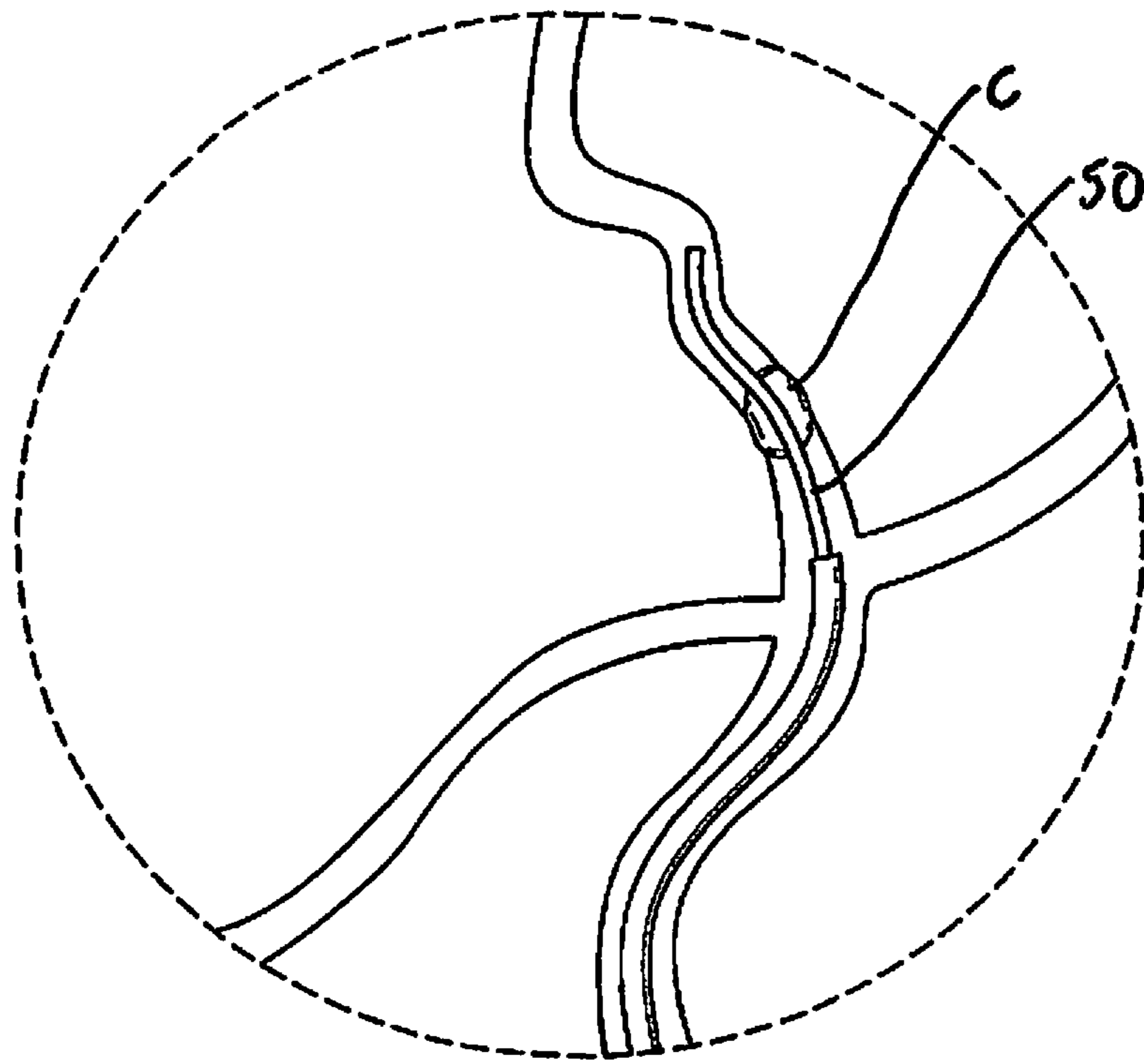


FIG. 14B

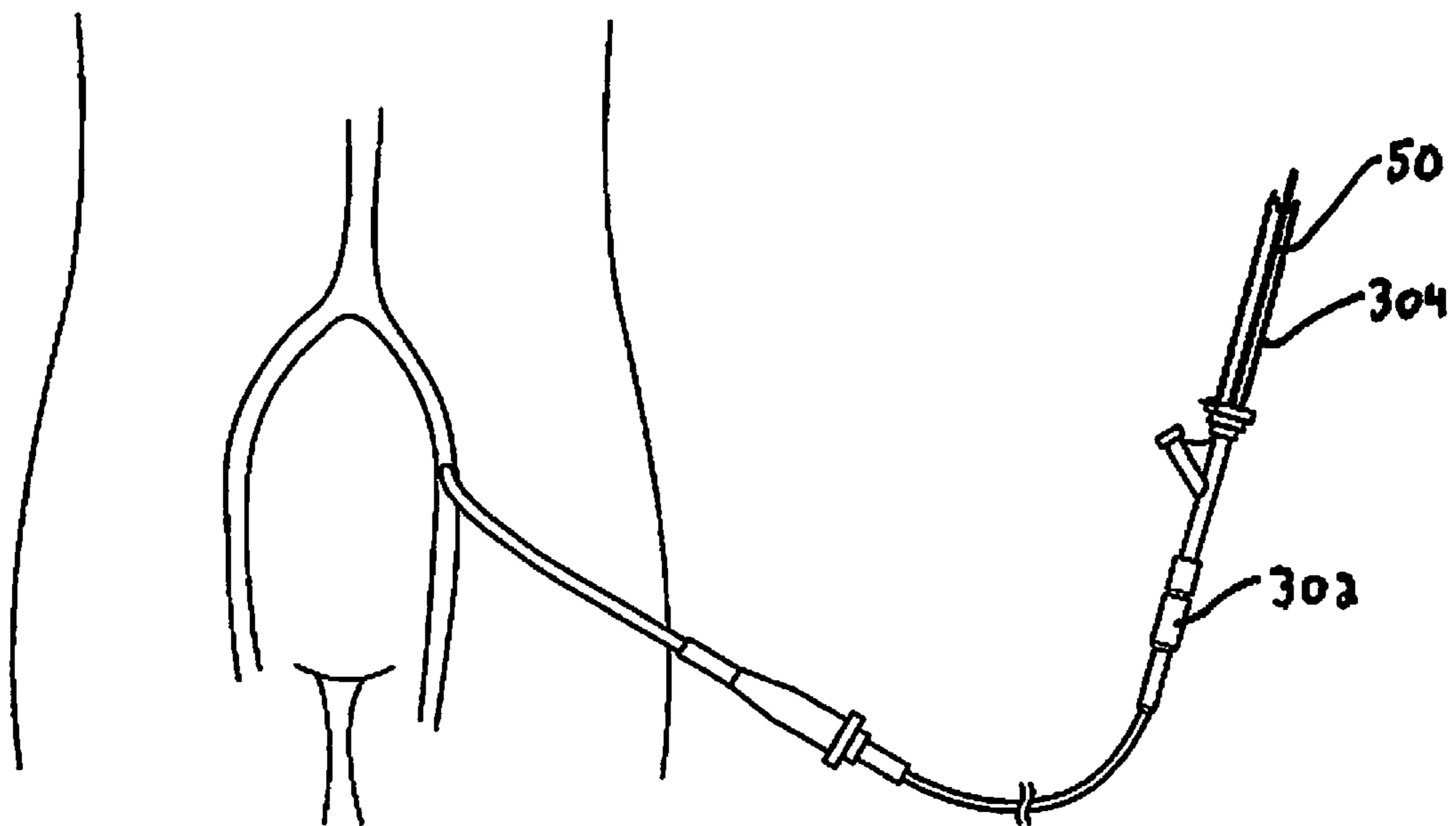
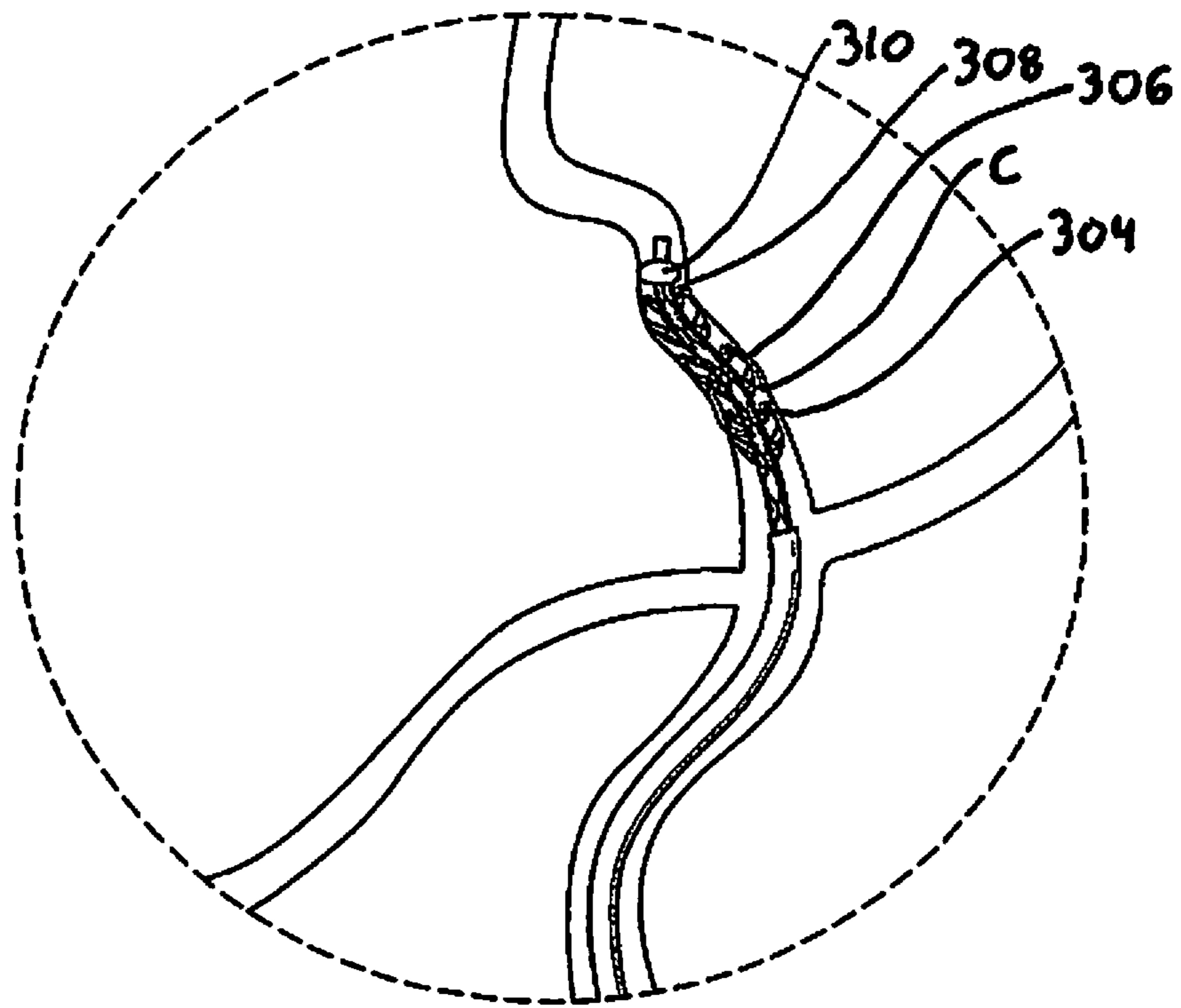


FIG. 14C

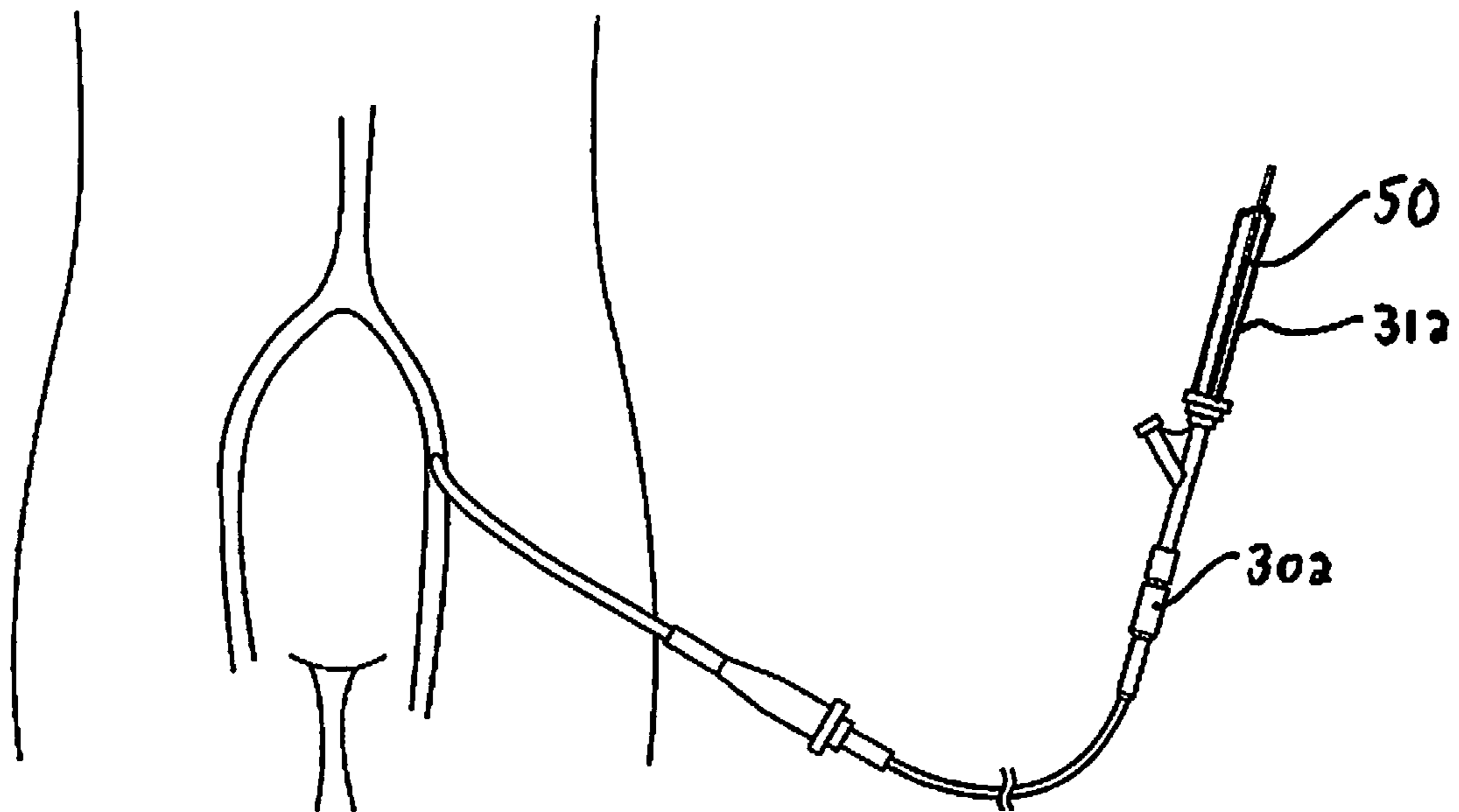
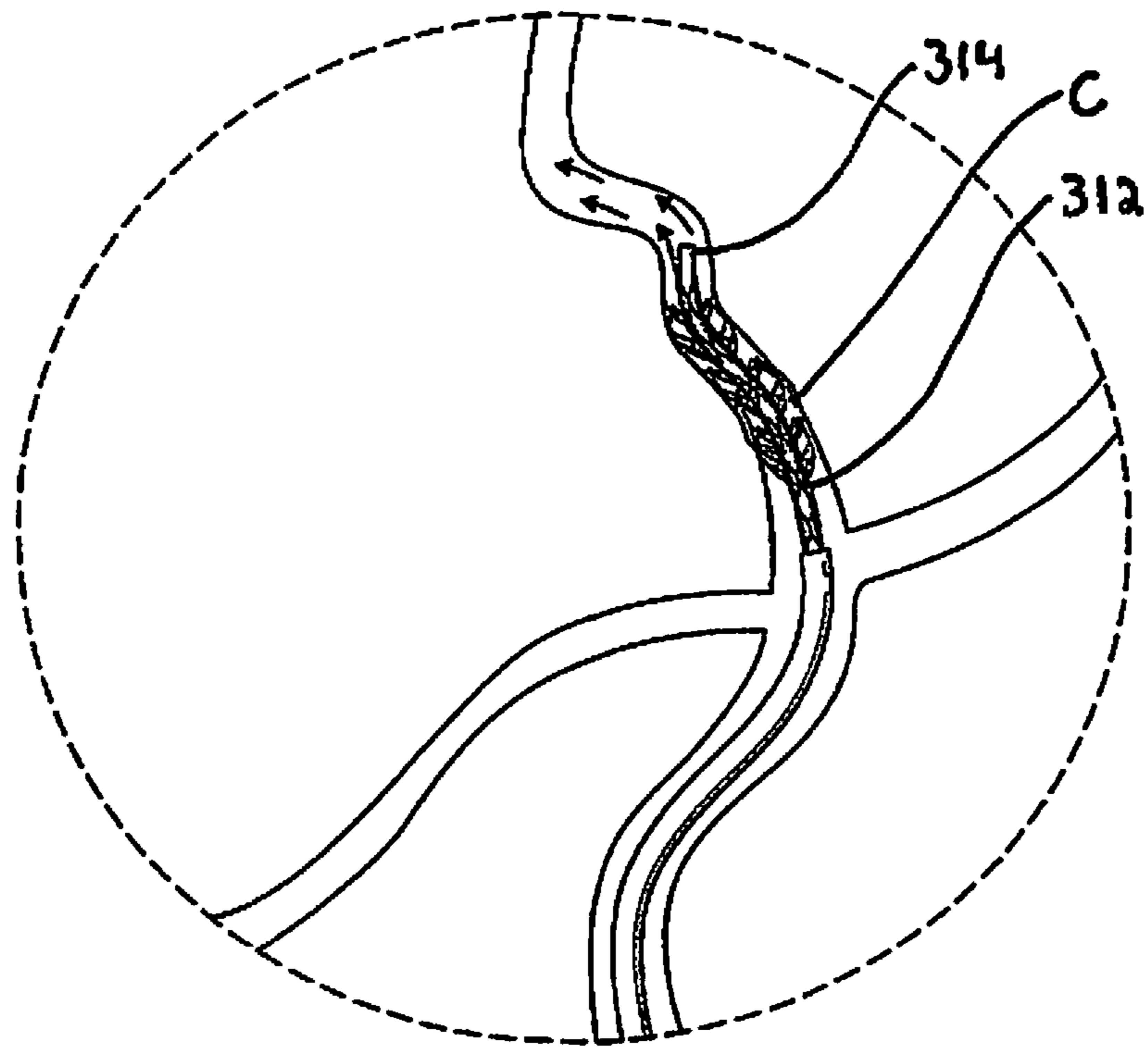


FIG. 14D

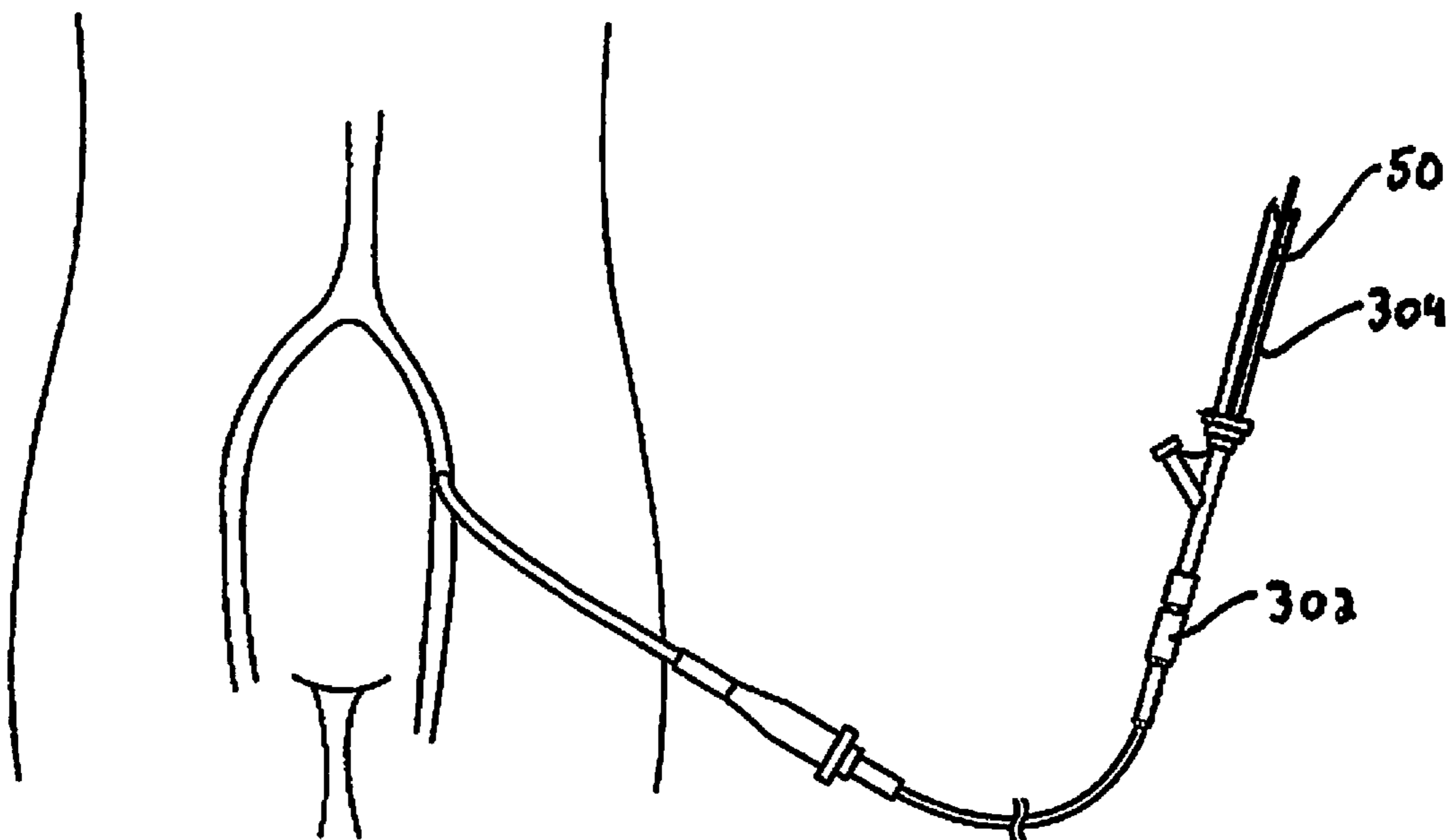
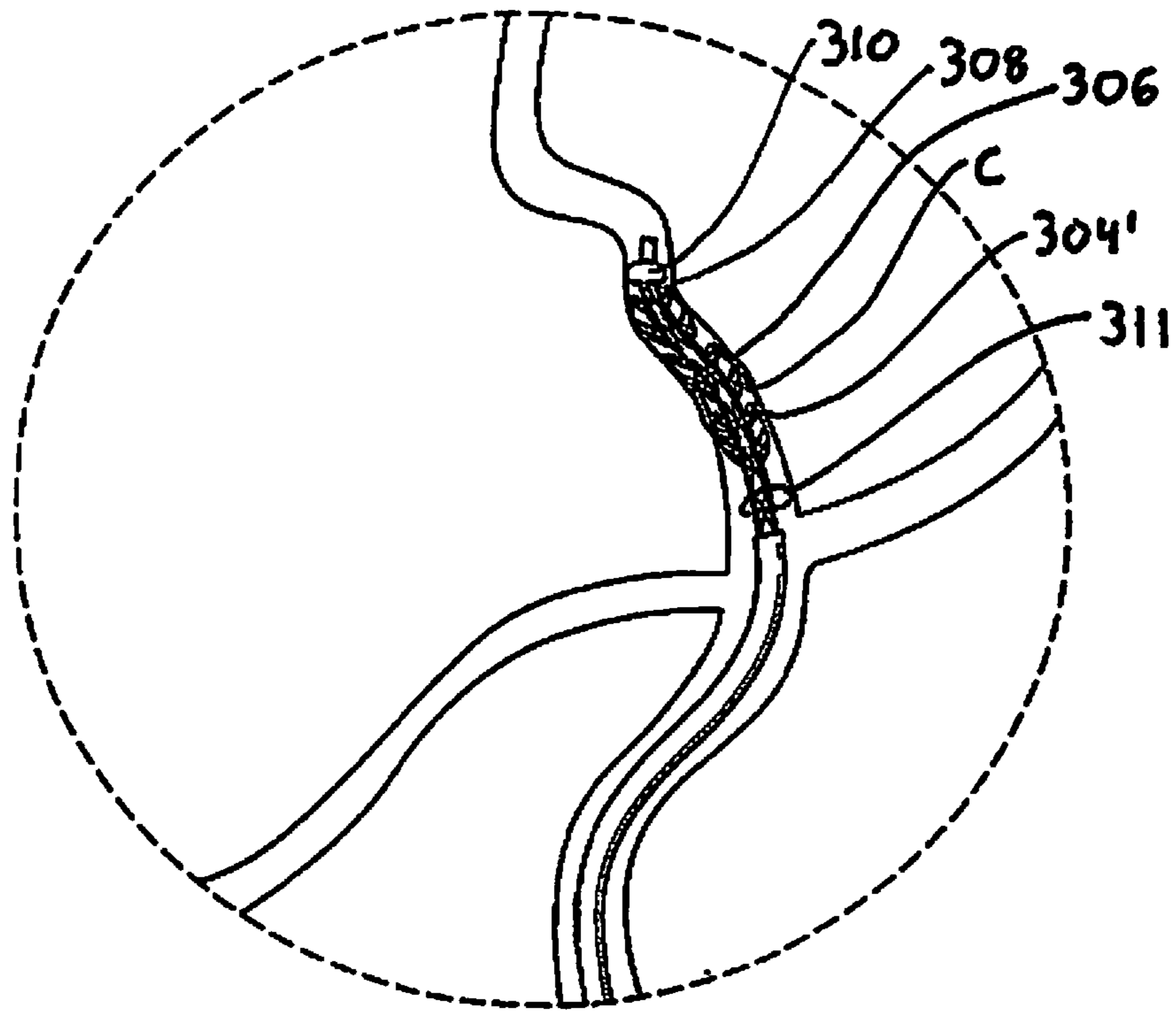


FIG. 14E

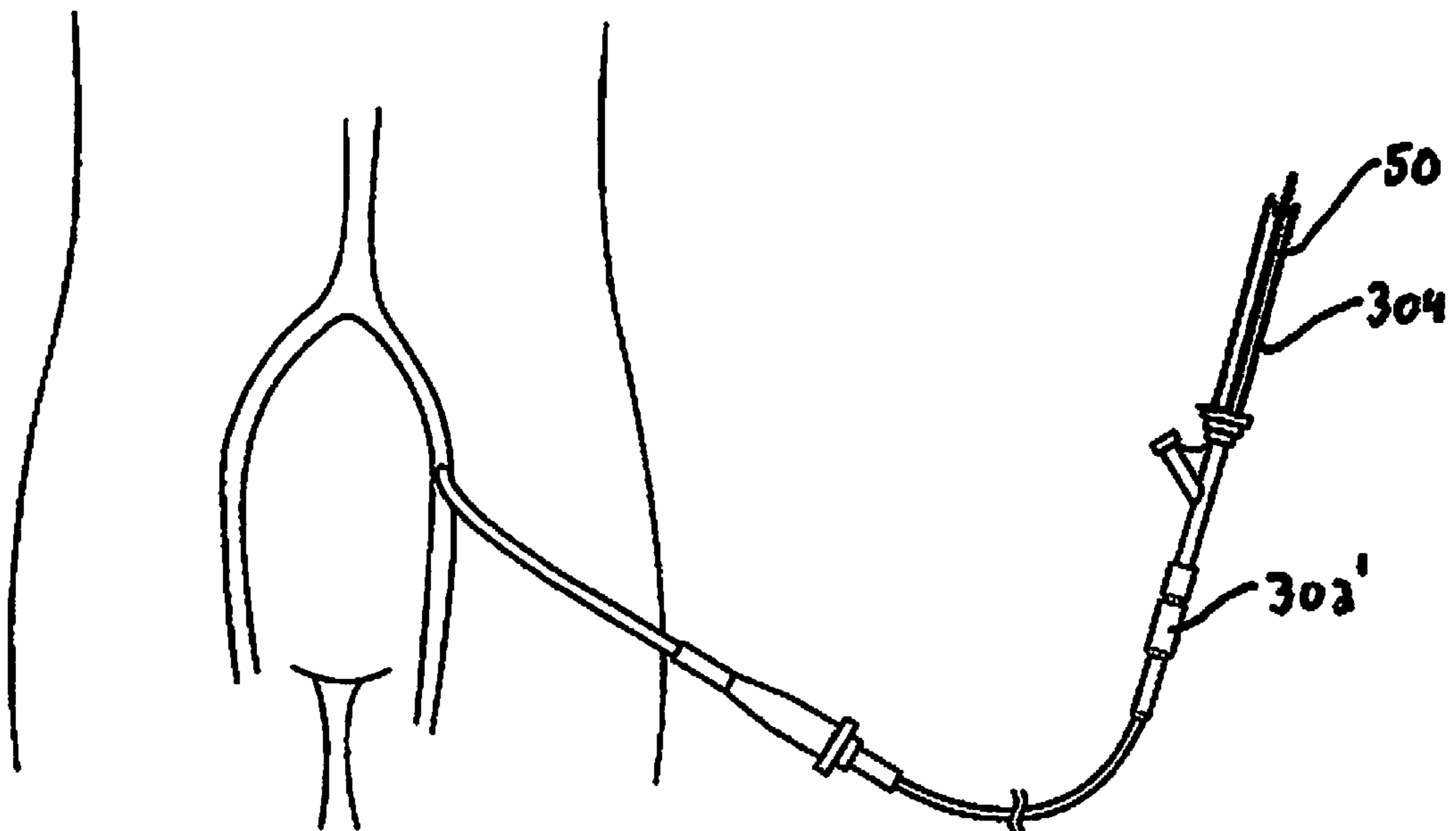
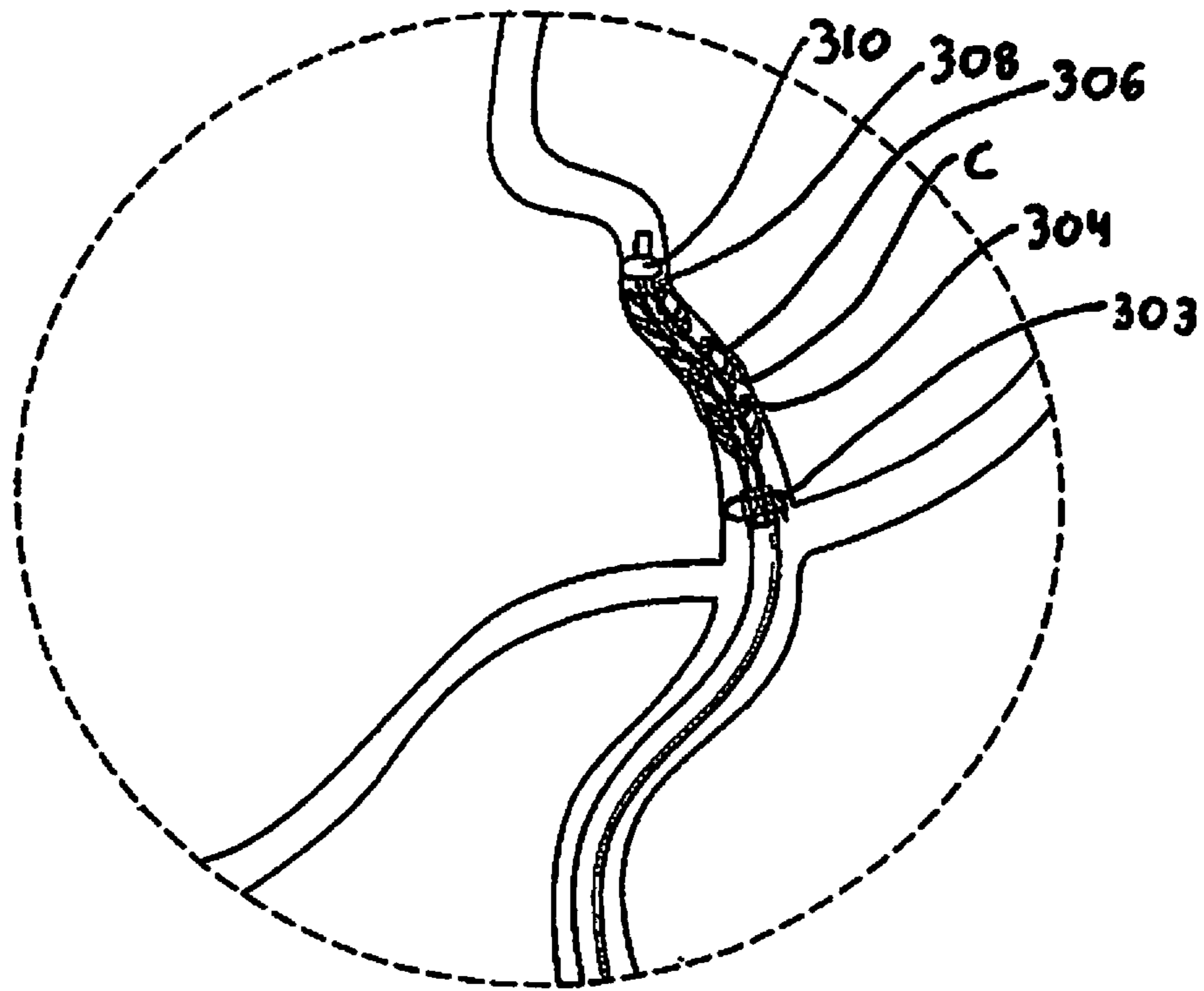


FIG. 14F

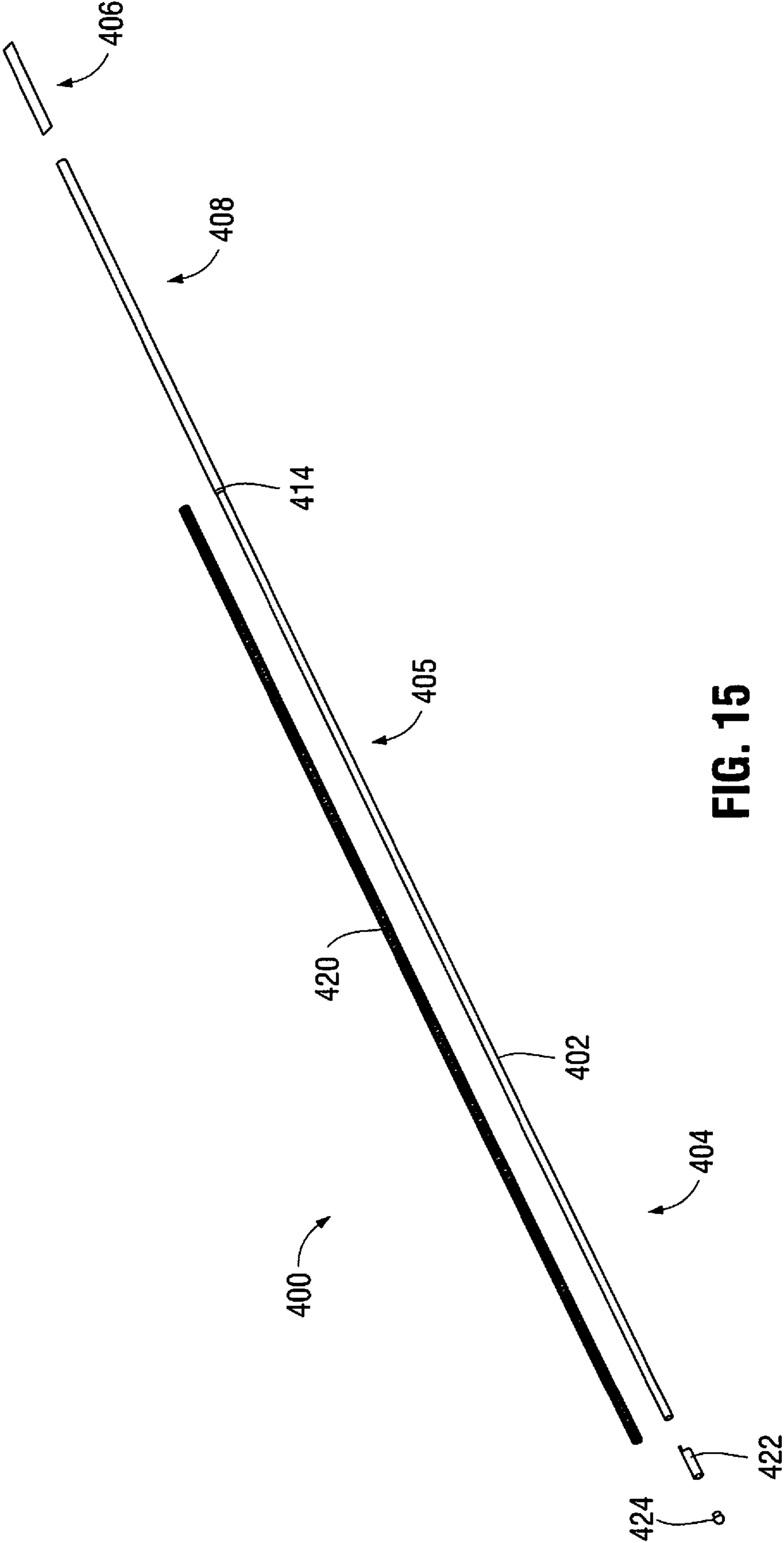


FIG. 15

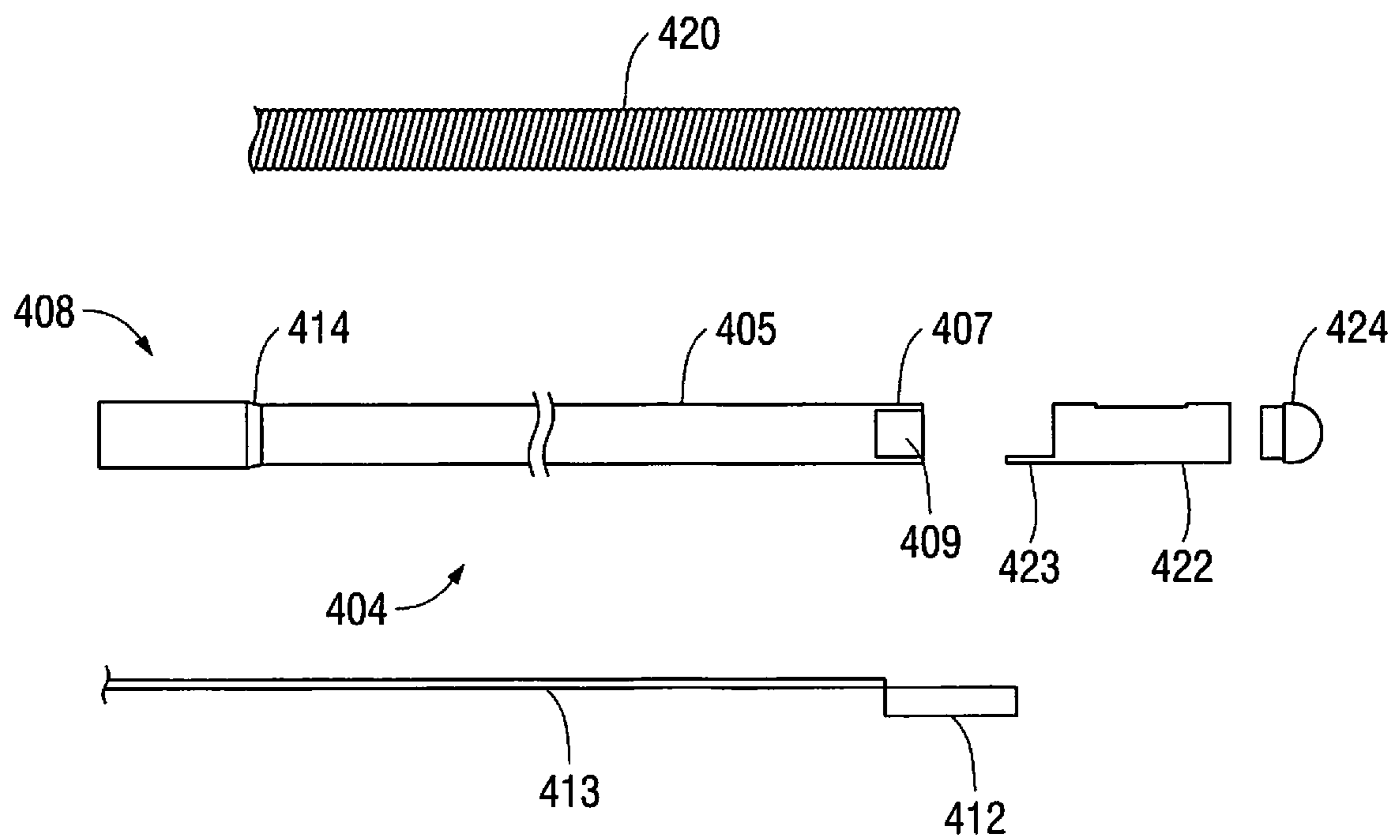


FIG. 16

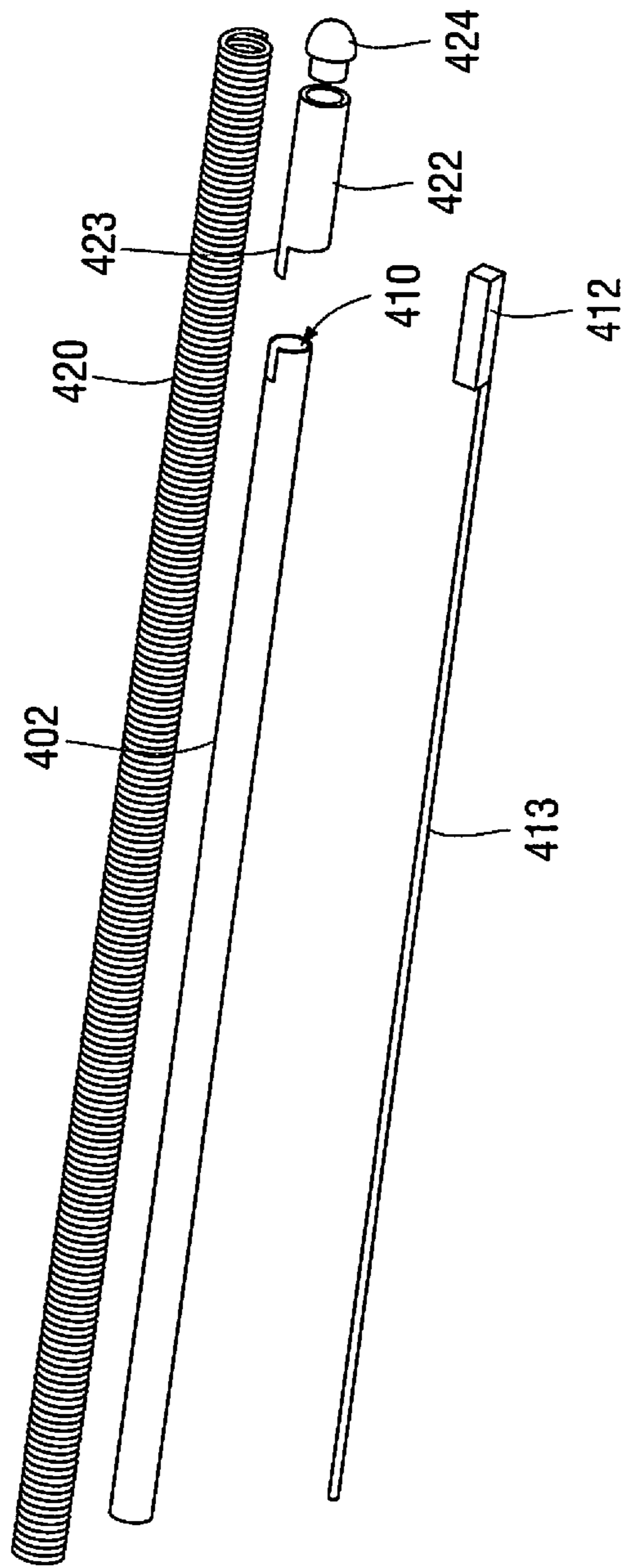


FIG. 17

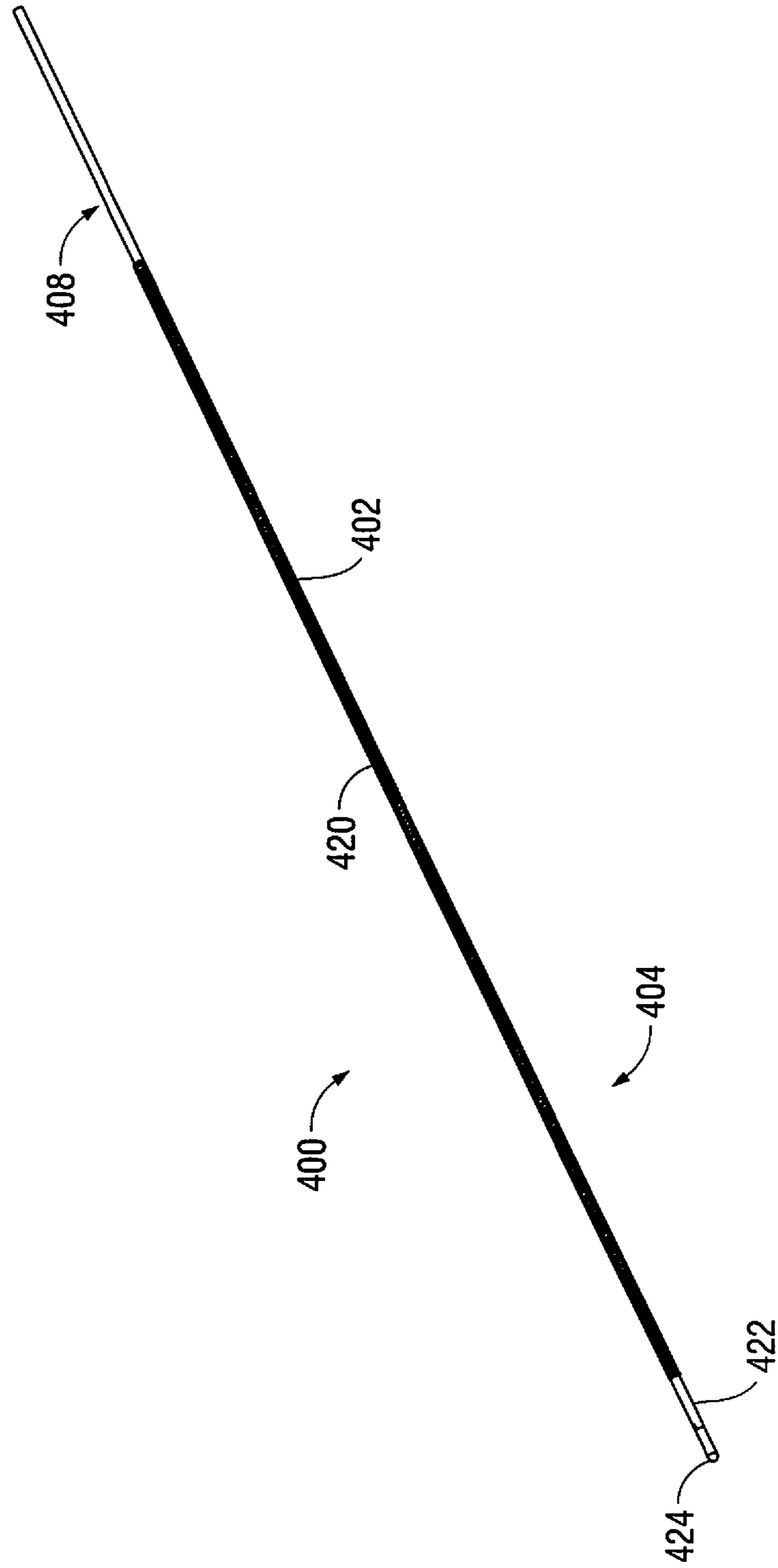


FIG. 18

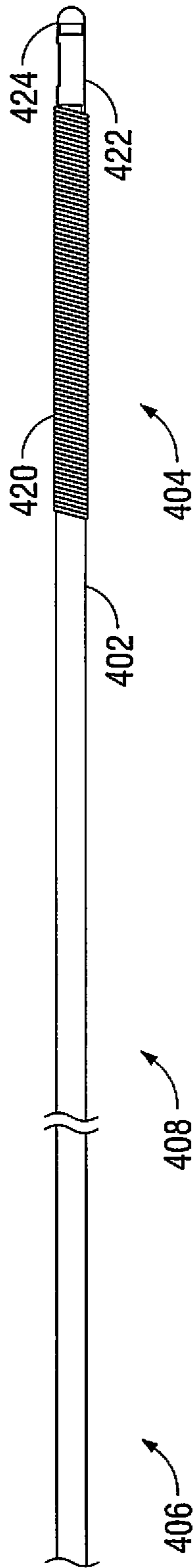


FIG. 19

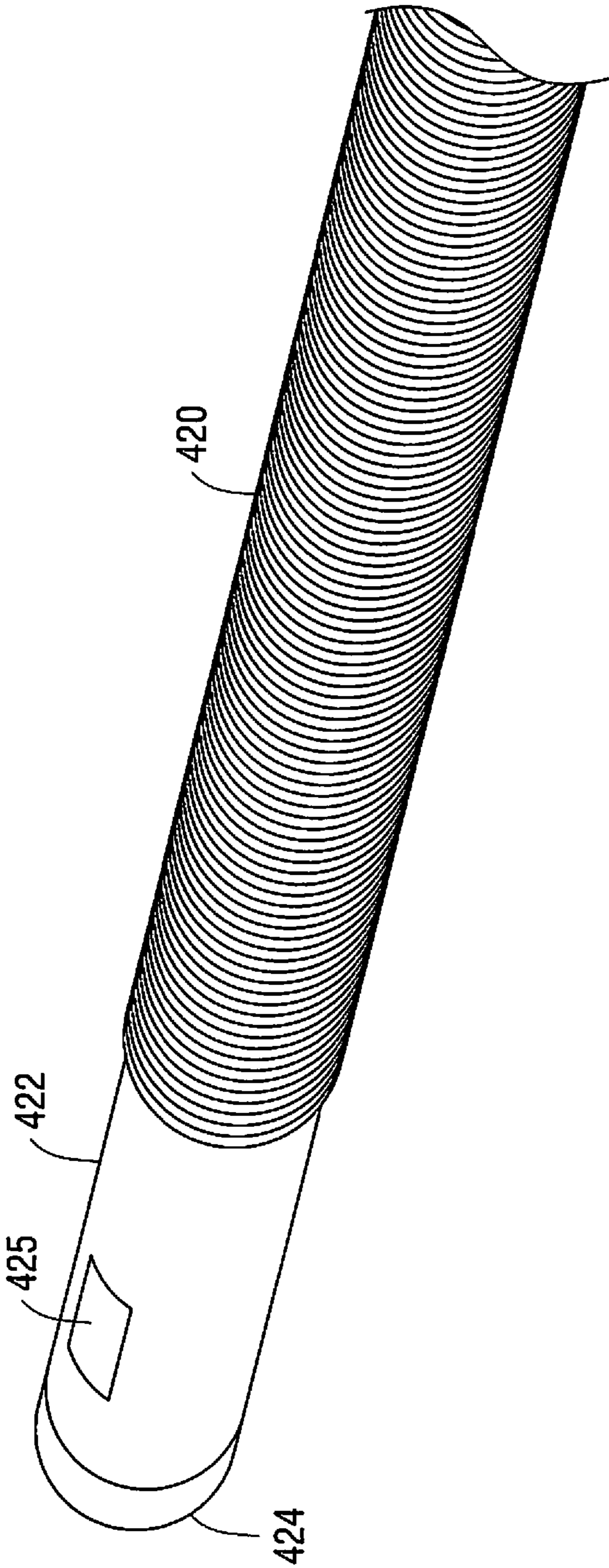


FIG. 20A

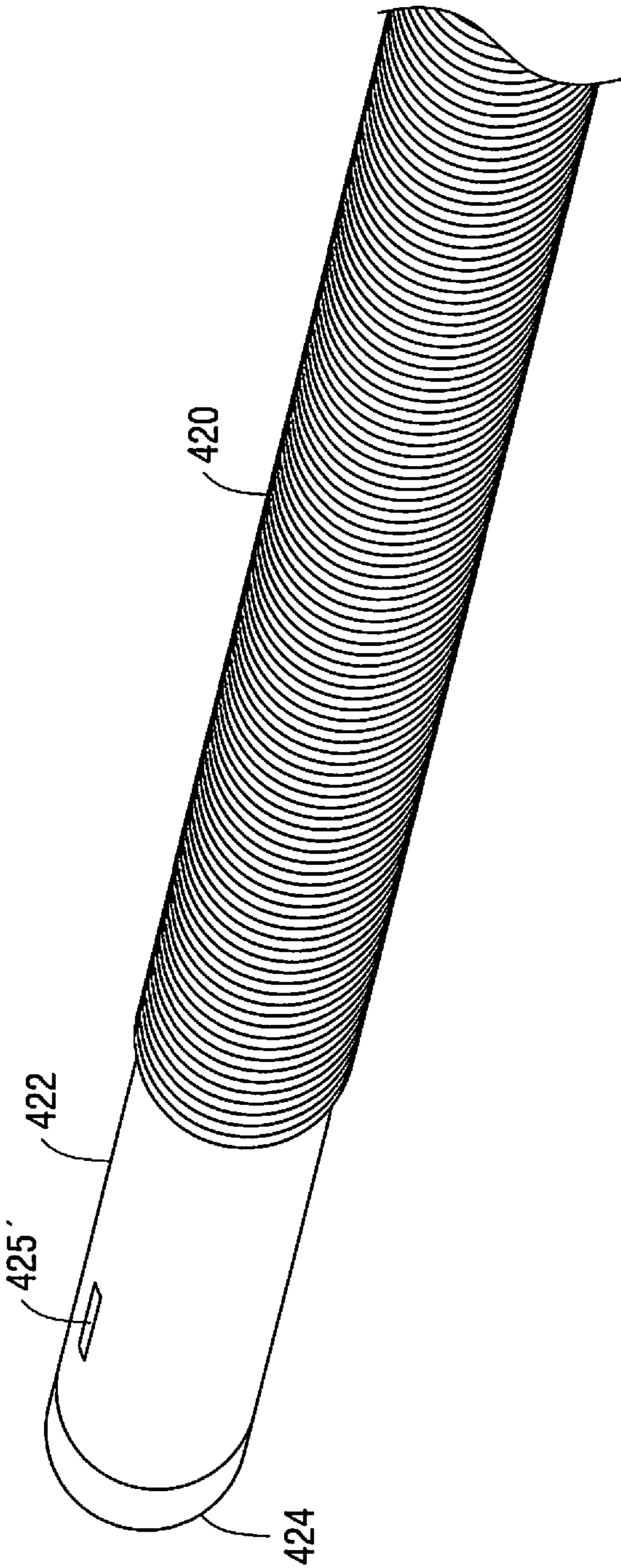


FIG. 20B

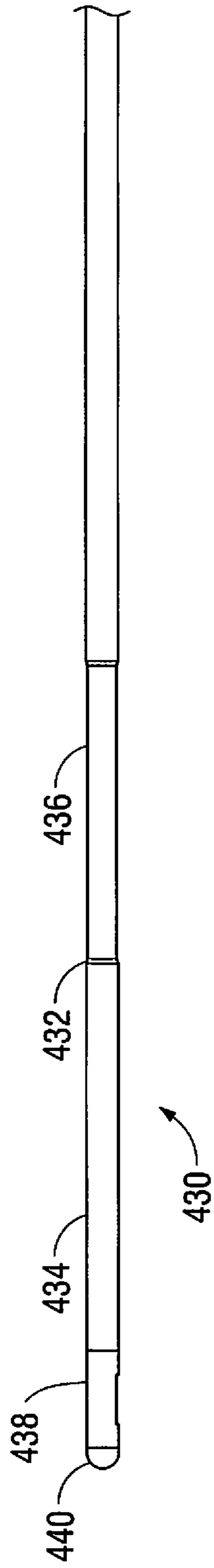


FIG. 21

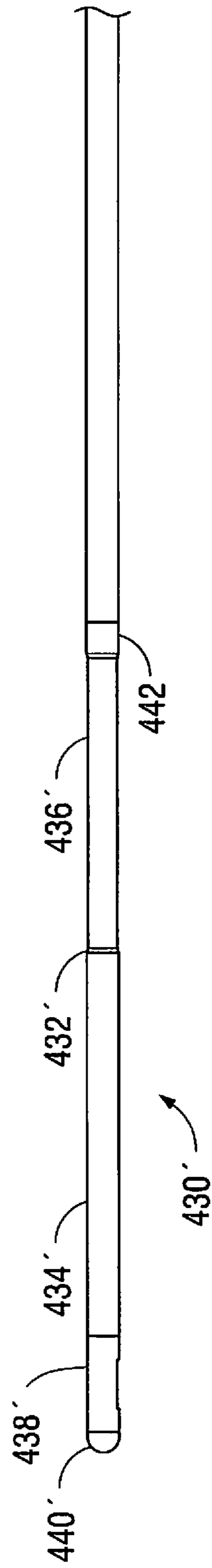


FIG. 22

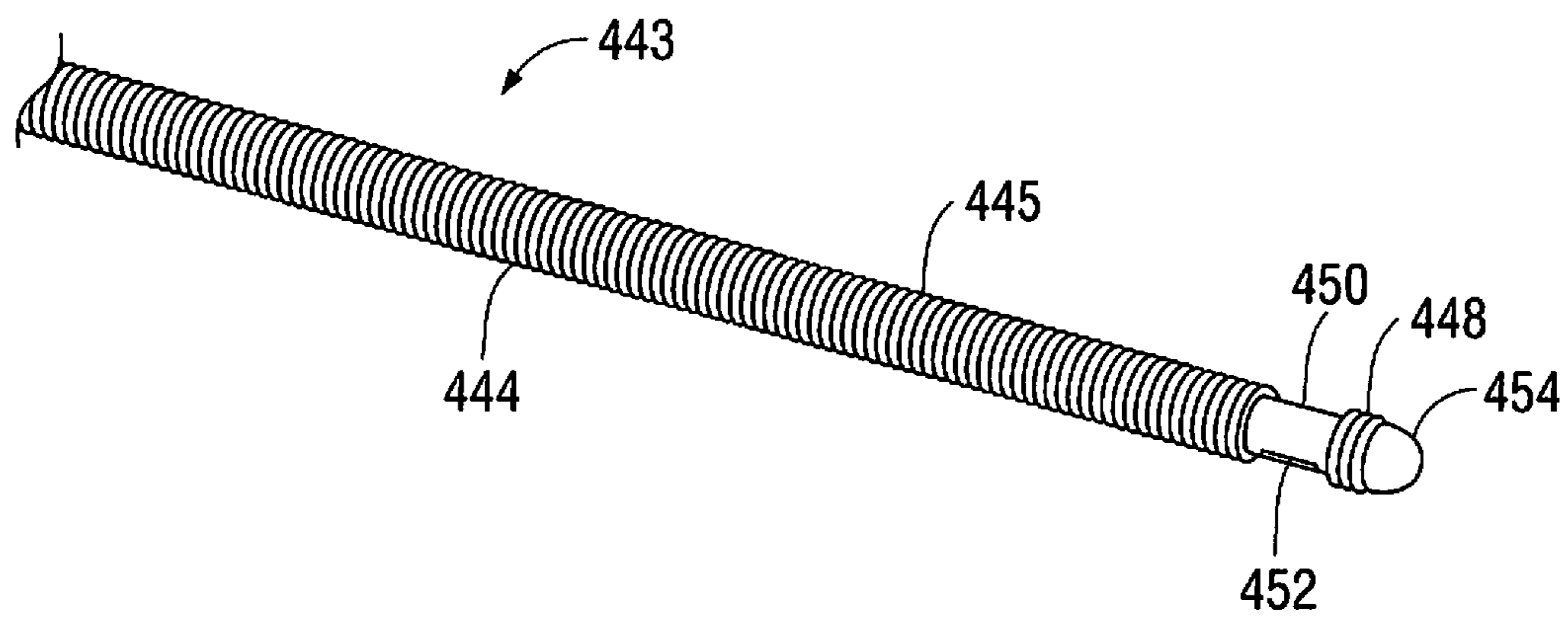


FIG. 23

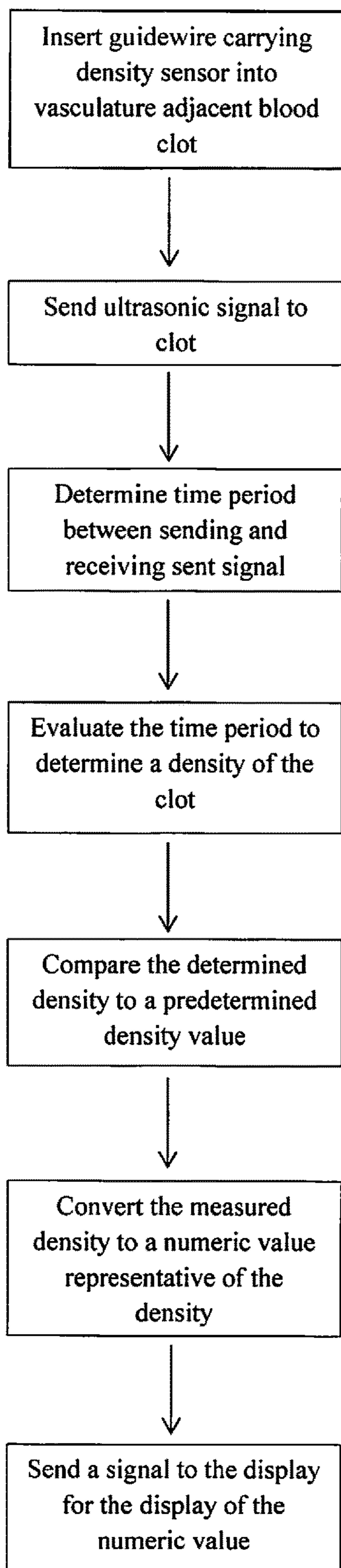


Figure 24A

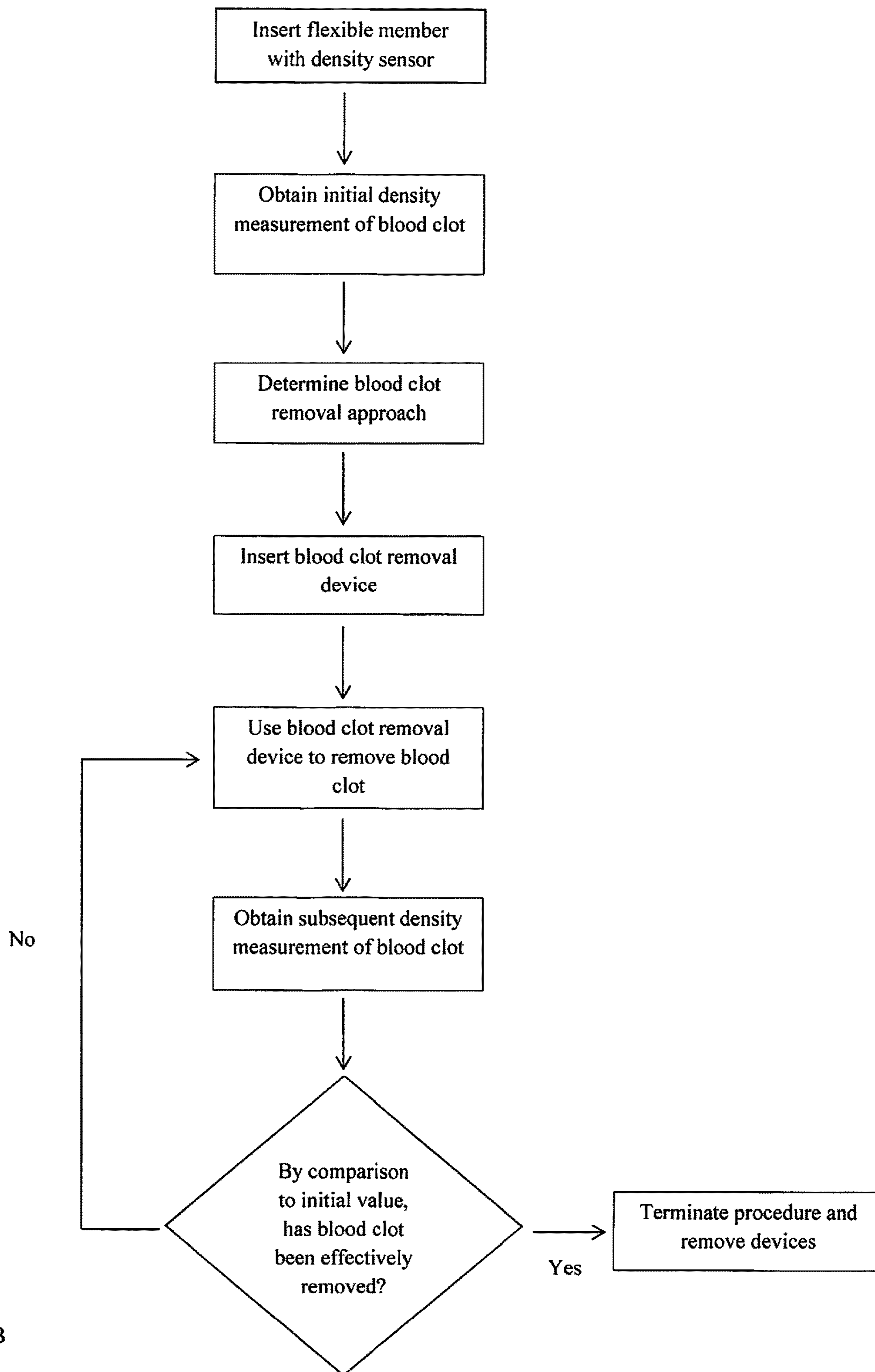
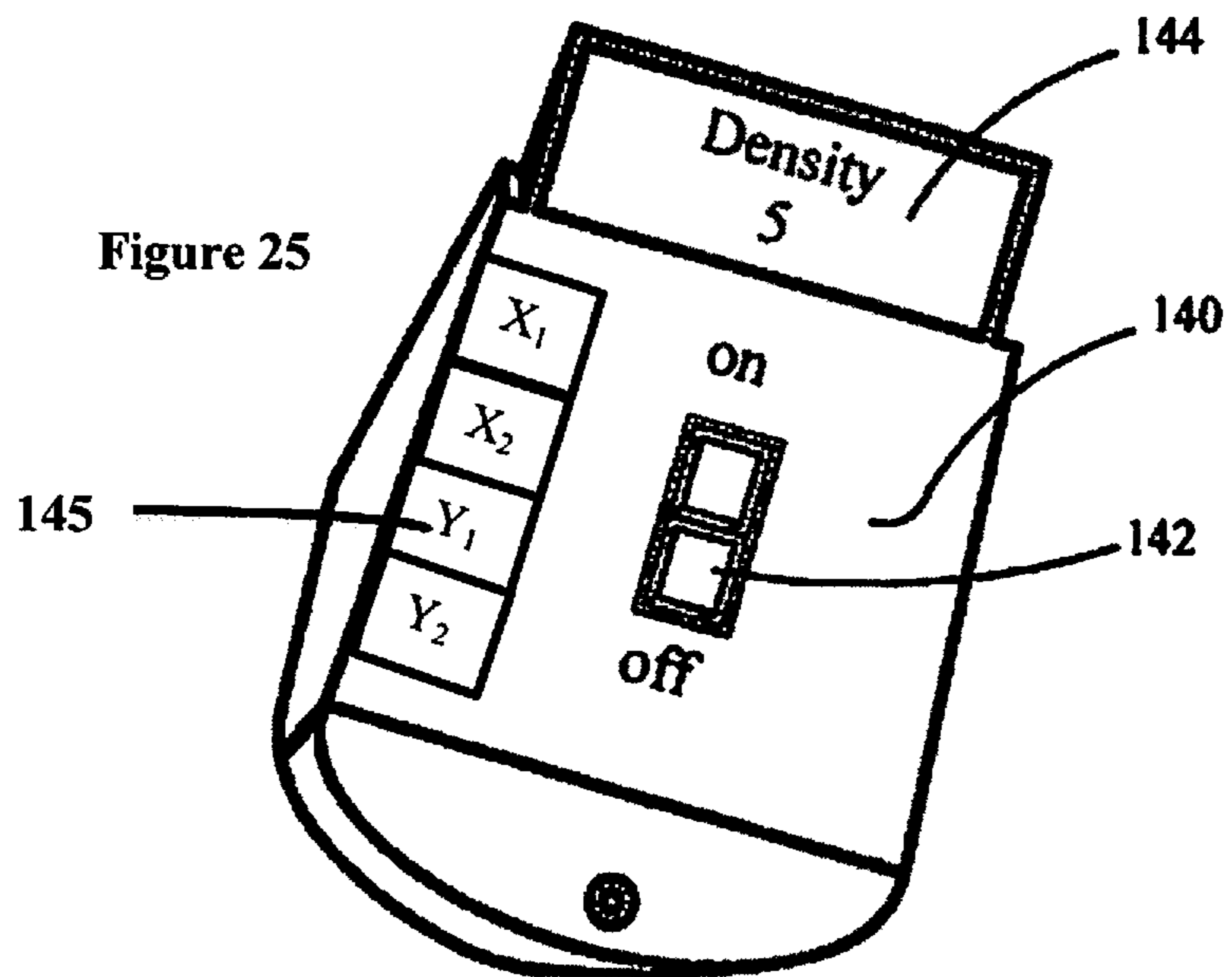


Figure 24B



FLEXIBLE MEDICAL DEVICE WITH MARKER BAND AND SENSOR

This application claims priority from provisional application Ser. No. 62/313,711, filed Mar. 26, 2016, the entire contents of which are incorporated herein by reference.

BACKGROUND

Technical Field

This application relates to a flexible medical device, and more particularly to a flexible medical device with a sensor.

Background of Related Art

Cerebrovascular disease refers to diseases of the brain caused by vascular abnormalities which result in abnormal cerebral blood flow. The most common cause of cerebrovascular disease is narrowing of the major arteries supplying blood to the brain, resulting in thrombogenic disease or sudden occlusion of blood flow, which if large enough results in ischemic stroke.

Clots (Ischemic Stroke) can originate in various areas and be caused by different modalities. These different modalities create clots that vary in consistency. The clot can be platelet rich (runny) or fibrin rich (hard) or anywhere in between the two. Ischemic stroke is caused by the thrombosis of a major vessel supplying blood to a region of the brain. A shortage of blood in the cerebral tissue leads to the deletion of metabolites such as oxygen and glucose, which in turn causes depletion of energy stores of the cells. Therefore, it is critical to remove the clots to restore adequate blood supply to the brain.

Current treatments for clot removal include application of thrombolytic drugs to dissolve the clot, aspiration, and mechanical thrombectomy devices in minimally invasive procedures. A problem encountered with these approaches is that the composition of the clot is undetectable in situ, while the efficacy of these approaches is dependent in part on the clot composition. Therefore, the physician is taking one of the known approaches for treatment of the clot without the knowledge of the clot makeup, e.g., its consistency. This can lead to inconsistent results as well as failure to properly treat the clot.

It would therefore be beneficial if the surgeon could identify the type of clot beforehand to better assess how the clot could be treated. Such prior knowledge would greatly enhance clot removal as the surgeon can adapt the approach to better match the treatment device or drugs with the type of clot.

Although techniques for identifying characteristics of blood clots are known, the need exists for a simple, reliable, easy to use and low profile system for clot assessment. It would also be beneficial to provide such system which can effectively assess blood clot characteristics at various times during the procedure.

Moreover, in addition to determining the type of blood clot, it would also be beneficial to assess whether the blood clot has been effectively removed during the procedure without relying on current methods, such as injecting contrast, which can have adverse effects such as re-compacting the clot.

In addition, in cerebrovascular disease, the vitality of the vasculature distal to the clot is compromised once the clot lodges in place. Vasculature that has been deprived of oxygenated blood will necrose and become friable. Once

blood flow is restored after clot removal, such blood flow could potentially cause a hemorrhagic event, which means the vessel can bleed out and burst open. Currently, surgeons do not have adequate knowledge of the vasculature downstream of the clot and therefore cannot accurately assess the risk of clot removal by for example dissolution, aspiration or mechanical thrombectomy.

It would be beneficial if the surgeon could determine the health of the vasculature distal to the clot prior to removal of the clot so the surgeon could determine if clot removal is advisable and/or take necessary precautions during clot removal so the vessels are not compromised. Prior attempts to measure pH using magnetic resonance imaging (MRI) technique have been attempted, as explained for example in “Modelling of pH Dynamics in Brain Cells After Stroke”, by Piotr Orłowski, et al., published in Interface Focus, The Royal Society, 2011. However, these attempts to date have been unsuccessful. Additionally, relying on MRI is very expensive and requires relatively complex mathematical models. Further, an ischemic event might need to be treated in an ambulance prior to arrival at a hospital and thus an MRI is not possible. Therefore, although the role of pH of the vasculature is recognized, the need exists to utilize this parameter to readily and inexpensively determine in hospital and non-hospital settings vascular tissue health to enhance blood clot removal or avoid clot removal where the risk is too great. This would provide great benefits not only for hospital treatment but for pre-hospital treatment such as in the ambulance or home prior to arrival at the hospital.

Additionally, after assessment of the health of the vasculature and selection of the proper clot treatment, it might be beneficial to control the restoration of blood flow. Being able to determine the health of the vasculature would thus advantageously enable gradual return of blood flow if deemed necessary to reduce the risk of hemorrhaging.

In treating cerebral arteries and other small arteries in the body, the challenge is to provide a device of sufficiently small size to navigate the small vessels and fit within the small vessel lumen while balancing the competing features of sufficient flexibility to navigate the tortuous vasculature and sufficient rigidity to enable pushability to the target site. The challenge of small size is exacerbated when the device needs to carry a sensor for detecting blood/vessel parameters and/or blot clot parameters.

SUMMARY OF THE INVENTION

The present invention provides in one aspect a system for determining a pH level of blood in a vessel of a patient comprising a flexible elongated device configured and dimensioned for insertion in the vessel of the patient and having a proximal portion, a distal portion and a tubular portion having a lumen formed therein. The elongated device is configured for insertion so the distal portion extends past a blood clot for positioning of the distal portion distal of the blood clot. A marker band is provided, at least a portion of which is positioned distally of the tubular portion. A sensor for positioning distal of the blood clot is positioned within the marker band. A connector operably connects the tubular portion to an indicator, the sensor measuring the pH level of blood downstream of the blood clot to thereby determine pH of the vessel downstream of the blood clot to determine the condition of the vessel to assess subsequent treatment of the blood clot, the indicator providing an indication of the pH measured by the sensor.

In some embodiments, the tubular portion comprises a hypotube. In some embodiments, the tubular portion has a

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first wall thickness and the marker band has a second wall thickness, the second wall thickness being less than the first wall thickness. In one exemplary embodiment, the first wall thickness is between about 0.002 inches and about 0.004 inches and the second wall thickness is between about 0.001 inches and about 0.002 inches. In some embodiments, the tubular portion has a martensitic distal region and an austenitic proximal region.

In some embodiments, the tubular portion has a first outer diameter and the marker band has a second outer diameter substantially equal to the first outer diameter. The marker band can in some embodiments have a window or cutout to enable communication of the sensor with the blood in the vessel. In some embodiments, the tubular portion has a first reduced diameter region at the distal region, and a radiopaque coil is positioned on the first reduced diameter region. In some embodiments, a second marker band is positioned proximal of the first marker band. In some embodiments, the tubular portion has a second reduced diameter region formed proximal of the first reduced diameter region to support a vascular implant. In some embodiments, the sensor has a wire extending through the lumen of the tubular portion.

In some embodiments, the system includes a second sensor for sensing a parameter of the blood clot and a second indicator to indicate the sensed parameter, the second sensor connected to the second indicator. In some embodiments, the second sensor senses a density of the blood clot.

In accordance with another aspect of the present disclosure a system for determining a pH level of blood in a vessel of a patient is provided comprising a flexible elongated device configured and dimensioned for insertion in the vessel of the patient, the elongated device having a proximal portion, a distal portion and a tubular portion having a lumen formed therein. The elongated device is configured for insertion so the distal portion extends past a blood clot for positioning of the distal portion distal of the blood clot, the elongated device having a lumen formed therein. A sensor is carried by the flexible elongated device for positioning distal of the blood clot. A locator on the elongated device indicates a position of the sensor within the vessel and an indicator positioned outside the patient communicates with the sensor, the indicator indicating a measured parameter of the blood.

In some embodiments, the sensor measures a pH level of the blood downstream of the blood clot to determine the condition of the vessel to assess one or both of a) treatment of the blood clot in response to the pH level indicated by the indicator; and b) desired blood flow rate after blood clot removal. In some embodiments, the locator is a marker band positioned distal of the tubular portion, the sensor positioned within the marker band and the marker band having a window to enable communication of the sensor with the blood. In other embodiments, the sensor measures the density of the clot. In some embodiments, the locator includes a first radiopaque coil positioned on the tubular portion and a second radiopaque coil positioned on the tubular portion proximal of the first radiopaque coil, and a gap is formed between the first and second radiopaque coils forming an exposed region having a window, the sensor positioned within the tubular portion and aligned with the window.

In accordance with another aspect of the present invention a method for determining a pH level of blood downstream of a blood clot in a vessel of a patient is provided comprising the steps of:

providing an elongated flexible device having a radiopaque marker band and a sensor positioned within the marker band;

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inserting the flexible device through vasculature of the patient and past the blood clot to a position downstream of the blood clot in the vessel, the marker band indicating to the user the position of the sensor;

sensing a pH level of the blood downstream of the blood clot; and

indicating to the user the pH level of the blood to enable the user to determine a pH level of the vessel downstream of the blood clot for subsequent selection of a clot treatment method.

In some embodiments, the method further comprises the step of determining a density of the blood clot to determine a clot treatment method. In some embodiments, a connector is provided connecting the flexible device to a visual indicator.

BRIEF DESCRIPTION OF THE DRAWINGS

Preferred embodiments of the present disclosure are described herein with reference to the drawings wherein:

FIG. 1 is a side view of a first embodiment of the system of the present invention illustrating a catheter coupled to a pH reader and showing the catheter tip positioned distal of the blood clot;

FIG. 2A is a close up perspective view of the pH reader of FIG. 1;

FIG. 2B is a close up perspective view of an oxygen level reader;

FIG. 3A is a close up view of the catheter tip of FIG. 1 showing the pH sensor on an outer surface of the catheter for determining blood pH;

FIG. 3B is a close up view of the catheter tip showing the pH sensor embedded in the wall of the catheter in accordance with an alternate embodiment;

FIG. 4 is a close up perspective of the coupler of FIG. 1 for connecting the pH reader cable to the catheter;

FIG. 5 is a close up view of the vasculature illustrating the catheter tip of FIG. 1 positioned past a blood clot;

FIG. 6 is a side view of an alternate embodiment of the system of the present invention illustrating a guidewire coupled to a pH reader and showing the guidewire positioned distal of the blood clot;

FIG. 7 is a close up perspective view of the coupler connecting the pH reader cable to the guidewire;

FIG. 8A is a close up view of the guidewire of FIG. 6 positioned distal of the clot and showing the pH sensor on the outer tip of the guidewire;

FIG. 8B is a cutaway view showing the pH sensor embedded in the wall of the guidewire in accordance with an alternate embodiment;

FIG. 8C is a close up view of an alternate embodiment having a pH sensor spaced from the distal tip;

FIG. 9A is side view of an alternate system of the present invention illustrating a catheter coupled to a density reader and showing the catheter tip positioned distal of the blood clot;

FIG. 9B is a close up view of the distal portion of the catheter of FIG. 9A showing the density sensor within the clot;

FIG. 10 is a close up view of the density reader of FIG. 9A showing a clot density reading;

FIG. 11A is a side view of an alternate embodiment of the system of the present invention illustrating a guidewire coupled to a density reader and showing the guidewire positioned distal of the blood clot;

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FIG. 11B is a close up view of the distal portion of the guidewire of FIG. 11A, with the clot broken away to show the density sensor within the clot;

FIG. 12A is a side view of another alternate system of the present invention showing a catheter coupled to a pH reader and a guidewire coupled to a density reader, and further showing the catheter tip and guidewire positioned distal of the blood clot;

FIG. 12B is a close up view of the distal end of the catheter and guidewire of FIG. 12A, showing retraction of the catheter to expose the density sensor on the guidewire;

FIG. 13 is an enlarged view of the density and pH reader of FIG. 12A;

FIG. 14A is a side view illustrating the introducer sheath positioned in the femoral artery and the guide catheter shown advanced into the cerebral artery;

FIG. 14B is a side view similar to FIG. 14A showing the guidewire of the present invention advanced through the guide catheter and past the cerebral blood clot;

FIG. 14C is a side view similar to FIG. 14B showing a microcatheter for treating the blood clot advanced over the guidewire, and further showing the balloon of the microcatheter inflated to cause slow reperfusion as the blood clot is removed;

FIG. 14D is a side view similar to FIG. 14C showing an alternate embodiment of a microcatheter for treating the blood clot advanced over the guidewire, and further showing the injection of cryogenic fluid to enable slow reperfusion as the blood clot is removed;

FIG. 14E is a side view similar to FIG. 14C showing an alternate embodiment of a microcatheter for treating the blood clot advanced over the guidewire, and further showing the balloon of the microcatheter inflated as the blood clot is removed;

FIG. 14F is a side view similar to FIG. 14E showing an alternate embodiment with a balloon on the guide catheter;

FIG. 15 is an exploded perspective view of an elongated flexible device in accordance with an alternate embodiment of the present invention;

FIG. 16 is an exploded perspective view of the distal region of the flexible device of FIG. 15;

FIG. 17 is an exploded perspective view of the distal region of the flexible device of FIG. 15;

FIG. 18 is a perspective view of the flexible device of FIG. 16;

FIG. 19 is a side view of the flexible device of FIG. 15;

FIG. 20A is an enlarged perspective view of the distal region of the flexible device of FIG. 15;

FIG. 20B is a perspective view of the distal region of an alternate embodiment of the flexible device.

FIG. 21 is a side view of an alternate embodiment of the flexible device of the present invention having a reduced diameter region to support a vascular implant;

FIG. 22 is a side view of another alternate embodiment of the flexible device of the present invention having a reduced diameter region;

FIG. 23 is a perspective view of the distal portion of another alternate embodiment of the flexible device of the present invention;

FIG. 24A is a flow chart showing the steps for density measurement and indication in accordance with one embodiment of the present invention;

FIG. 24B is a flow chart illustrating the method steps for density tracking of the blood clot in accordance with one embodiment of the present invention; and

FIG. 25 is a close up view of an alternate embodiment of the density reader of the present invention.

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DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

The present invention provides a system for determining the type of blood clot. This enables the clinician to assess the best mode of treatment of the blood clot. The present invention further provides a system which can track blood clot removal. The present invention also provides a system for determining the health or condition of the vasculature distal of the blood clot. This aids the clinician in assessing the effect of removal of the blood clot from the vessel. This can also enable the clinician to assess the rate of reperfusion desirable post clot treatment. The foregoing systems can be used independently, or alternatively, two or more of the foregoing systems can be used together. That is, it is contemplated that only one of the systems is utilized so the user measures only one of the parameters, e.g., health of vasculature or type of clot. However, it is also contemplated that two or more of the systems can be utilized so the user can determine the foregoing parameters plus determine, if desired, if the clot has been effectively removed and/or a desired rate of reperfusion. These systems are described in detail below.

Vasculature Determination

Turning first to the system for determining the health or condition of the vasculature, this system is illustrated in FIGS. 1-8, with FIGS. 1-5 illustrating an embodiment where the pH sensor is located on a catheter and FIGS. 6-8B illustrating an embodiment where the pH sensor is located on a guidewire. It is also contemplated that a pH sensor can be positioned on the catheter and on the guidewire, and it is also contemplated that one or more pH sensors can be positioned on the catheter and one or more pH sensors can be positioned on the guidewire. Multiple sensors would enable different regions of the blood (and therefore the vasculature) to be measured. In certain embodiments, utilizing multiple pH sensors, the sensors can be spaced apart sufficiently so that a pH measurement can be taken both upstream and downstream of the blood clot for comparative purposes in assessing vasculature health.

The system for measuring pH is beneficial since in certain instances the vitality of the vasculature distal to the blood clot is compromised once the clot lodges in place. Vasculature that has been deprived of oxygenated blood will necrose and become friable. Once blood flow is restored after clot removal, such blood flow could potentially cause a hemorrhagic event, which means the vessel can bleed out and burst open. Therefore, this system provides a way of determining the health of the vasculature distal to the clot so the physician could determine if clot removal is advisable to determine the best method to remove the clot or take other precautions during clot removal. That is, the physician will be able to determine if the clot should be removed based upon the pH content of the vasculature distal to the clot, and if removal is desirable, assess the best way to restore blood flow as the clot is removed.

Such determination can be done measuring pH of the blood. Thus, the pH level of blood, measured in a simplified cost effective mobile and efficient manner, is utilized to assess the condition of the vessel. That is, measuring the pH level of blood will provide the pH level of the vessel by the clot.

Note the vasculature health can also be accomplished in an alternate embodiment by sensing oxygen levels in the blood which would provide an indication of the health of the vasculature. Other parameters could also be measured.

With respect to pH, it is understood that intracellular pH is important in the maintenance of normal cell function. Blood pH is regulated by a system of buffers that continuously maintain its normal range of 7.35 to 7.45. Blood pH drop below 7 or above 7.45 can cause serious problems, including death. Studies have shown that carbon dioxide plays a vital role in blood pH abnormality. Carbon dioxide serves as a buffer. As carbon dioxide becomes depleted, the pH drops and acidosis and/or apoptosis occurs.

With the presence of a blood clot, there is essentially a closed system (or substantially closed system) created in the vasculature since blood flow downstream of the clot has mostly stopped. Being a closed system, the pH of the blood can be measured and the blood pH will be indicative of the pH of the adjacent vasculature. Thus, the measurement of the blood pH as described herein provides an inexpensive, accurate and effective way to determine (i.e., measure) the pH and thus the health of the adjacent vasculature. The blood pH can be measured utilizing known techniques such as an ionic potential sensor that converts the activity of a specific ion dissolved in a solution into an electric potential which can be measured. Known glass and crystalline membranes can be utilized. The sensor can be contained in a microchip. Fiber optics transmission can also be utilized.

It is also contemplated that instead of measuring blood pH, the oxygen level of the blood can be measured downstream of the blood clot, preferably in a closed or substantially closed system, to thereby determine the health of the vasculature.

The system of the present invention provides a quick and simple effective measurement of the blood downstream of the clot and enables a determination of blood clot treatment either during or prior to hospitalization, such as in the ambulance ride, wherein the treatment method can be determined so as to prevent cerebral hemorrhaging. This is accomplished without expensive and cumbersome equipment such as MRI machines.

The system in some embodiments not only enables determination of the optimized treatment of the blood clot but in cases where it determines blood clot removal is indicated, it enables control of reperfusion. That is, based on the pH measurement, it provides an indication whether restoration of normal blood flow as a result of clot removal is acceptable, i.e., whether the vessel is in condition to handle restoration of normal blood flow, or whether restoration of blood flow needs to be controlled, i.e., delayed and/or restored slowly until the pH level rises to an acceptable level. Several ways to control reperfusion are discussed below by way of example. Note that the system for measuring pH can be utilized prior to, during and after blood clot treatment to provide indications of pH levels of the blood and thus the vasculature at various times.

Turning more specifically to the system of FIGS. 1-5, catheter 10 has a proximal portion 12 and a distal portion 14. The catheter tube 16 is sufficiently flexible to navigate the small vessels while having some rigidity to enable it to be directed around the curves of the vasculature. An RHV (rotating hemostatic valve) 20 is attached to the catheter hub 22 and includes a side arm 24 for fluid injection and/or aspiration. Coupler (connector) 30 is attached to the catheter 10, and is connected to cable 34 which is connected to pH reader (meter) 40. In one embodiment, as shown in FIG. 4, the coupler 30 is u-shaped with opening 31 between the legs of the "u" dimensioned to frictionally clamp onto the outer wall of the catheter 10. That is, the coupler 30 is shown in the embodiment of FIG. 1 in the form of a U-shaped clip with the radius of the U smaller than that of the outer wall

of the catheter so it flexes outwardly when placed over the strain relief of the catheter and then is frictionally retained on the catheter. In another embodiment, a second connector (coupler) half is placed opposite the connector to form a 360 degree clip or clamp surrounding the outer wall of the catheter to retain the connector on the catheter 10. Other methods of attachment are also contemplated such as magnetic attachments. Cable 34 is connected to the coupler at one end 35 and connected at the opposing end 36 to reader 40. As shown (FIG. 1), the coupler 30 is attached to the region of catheter 10 just distal of hub 22, although other locations are also contemplated. The coupler 30 can be attached to the strain relief of the catheter 10 to enhance coupling.

The pH sensor 26 for measuring blood pH is positioned at the distal portion 14 of the catheter 10 and is electrically coupled to cable 34 via a pair of wires (not shown) extending from the sensor 26 to the coupler 30 and/or cable 34. The wires can be embedded in a wall of the catheter 10 or alternatively extend through a lumen in the catheter 10. In the embodiment of FIG. 3A, the sensor 26 is positioned on an outer wall of the catheter 10, extending circumferentially around 360 degrees. The sensor can also be incorporated into a marker band at the tip of the catheter 10 as discussed in detail below. In the alternate embodiment of FIG. 3B, the sensor 26' is positioned inside the catheter 10, either internal of the inner catheter wall or alternatively embedded in the wall of the catheter 10'. Wires 27 connect the sensor 26' to the coupler 30 and/or cable 34, with two lines coming into the reader 40 and extending to the sensor 26.

The pH reader 40 provides an indicator device and contains an on off switch 42. A reading 44 provides a visual indication, as a numeric value, of the measured pH of the blood to inform the user of the pH of the blood, and therefore the vasculature. FIG. 2 shows by way of example a reading of 6.4 which is below the normal range of 7.35 to 7.45 and thus indicates acidosis has likely occurred which affects (compromises) the vasculature structure.

In some embodiments, a pH level of 6.8 of the blood/vasculature is used as the parameter to modify the treatment modality. In other embodiments, the pH level of 6.4 is used as the parameter to modify the treatment modality. By way of example, 6.8 could be a first predetermined level where if the measured pH is at or below this level, the clinician would decide that blood clot removal provides some risk and the method of clot removal needs to be assessed. By way of example, 6.8 could be the threshold for assessing the type of treatment method and a pH level of 6.4 could be the predetermined level where the clot should not be removed because of the condition of the vasculature. In other embodiments, 6.0 could be the predetermined level at which the clot would not be removed.

In some embodiments, a pH level of 6.8 of the blood/vasculature is used as the parameter to modify post treatment reperfusion. In other embodiments, the pH level of 6.4 is used as the parameter to modify post treatment reperfusion. By way of example, 6.8 could be a first predetermined level where if the measured pH is at or below this level, the clinician would decide that blood flow restoration post blood clot removal is at risk and blood flow needs to be controlled to gradually restore blood flow. By way of another example, 6.4 can be the threshold for assessing the treatment method if the measured pH is at or below this level, the clinician would decide that blood flow restoration post blood clot removal is at risk and blood flow needs to be controlled to gradually restore blood flow.

Current treatments for clot removal include application of thrombolytic drugs to dissolve the clot, aspiration of the clot and mechanical thrombectomy devices in minimally invasive procedures. A problem encountered with these approaches is that the composition of the clot is undetectable in situ, while the efficacy of these approaches is dependent in part on the clot composition. Therefore, the physician is taking one of the known approaches for treatment of the clot without the knowledge of the clot makeup, e.g., its consistency. This can lead to inconsistent results as well as failure to properly treat the clot.

In use, the catheter **10** (or **10'**) can be inserted utilizing known methods, e.g., through a femoral approach or a brachial approach, and advanced through the vascular system to the desired treatment site, e.g. a cerebral artery A. The catheter tip **11** is advanced past the blood clot C (see e.g., FIG. 5). The sensor is activated to measure pH, with the pH reader turned on so that pH value can be determined. As noted above, the closed system advantageously enables the user to determine the vasculature condition, i.e., the pH of the vasculature by measuring the blood pH rather than the pH of the vasculature itself. Proper treatment approaches, e.g., deciding whether the clot can be safely removed, selecting the safest clot removal method or taking other precautions to protect the vessel, can then be implemented. Also, restoration of blood flow can then be controlled in accordance with the condition of the vessel.

FIGS. 6-8B illustrate an alternate embodiment for measuring pH utilizing a sensor on a guidewire instead of the catheter as in FIG. 1. This provides a reduced profile measurement system. It also provides a more flexible system to navigate tortuous vessels. Also, by being smaller it can be inserted more distal within the cerebral vasculature. It could also be more steerable and could traverse the clot easier. In some embodiments, by way of example, the outer diameter of the guidewire can be between about 0.010" and about 0.032", although other ranges of sizes are also contemplated. In some embodiments, the outer diameter can be about 0.014".

Guidewire **50** has a proximal portion **52** and a distal portion **54**. The guidewire **50** is sufficiently rigid to navigate the small vessels while having some rigidity to enable it to be directed around the curves of the vasculature. In one embodiment, the guidewire is hollow to form a lumen and the wire(s) runs through the lumen from the sensor to the connector. The wire(s), as in other embodiments herein, is preferably insulated. In another embodiment, the guidewire is a solid core and a polymeric jacket contains the insulated wire(s) on an outer surface of the guidewire. The guidewire **50** is illustrated within a lumen of a catheter **70** having a RHV **74** attached to the proximal end. The RHV **74** is attached to the hub **72** of the catheter **70** and includes a side arm **75** for injection and/or aspiration. Coupler **80** is attached to the guidewire **50**, and is connected to cable **83** which is connected to pH reader **40**, thus connecting the wire(s) of the sensor to the cable and reader **40**. The pH reader can be the same as in the embodiment of FIG. 1. In one embodiment, as shown in FIG. 7, the coupler (connector) **80** is u-shaped with opening **81** between the legs of the "u" dimensioned to frictionally clamp onto the outer wall of the guidewire **50**. A two part connector as described above could also be utilized. Other methods of attachment are also contemplated including magnetic attachments for example. Cable **83** is connected to the coupler **80** at one end **85** and connected at the opposing end **86** to reader **40**.

The pH sensor **56** is positioned at a distal end of the guidewire **50** and is electrically coupled to coupler **80** and/or

cable **83** via a pair of wires (not shown) extending from the sensor **56**. The wires can be embedded in a wall of the guidewire **50**, or alternatively, the guidewire can have a lumen or channel through which the wires extend. In the embodiment of FIG. 8A, the sensor **56** is positioned on an outer wall of the guidewire **50**, extending circumferentially around 360 degrees. The sensor can also be incorporated into a marker band at the tip of the guidewire **50** as described below. In an alternate embodiment, the sensor **56'** and wires **57** (only one is shown) of guidewire **50'** can be positioned inside the guidewire **50'**, either internal of the inner wall of the guidewire as shown in FIG. 8B, or alternatively embedded in the wall of the guidewire. The catheter **70** through which the guidewire extends can have a marker band **79** for imaging. Note in FIG. 8A, the catheter **70** and guidewire **50** are positioned in a cerebral artery A distal of clot C.

In use, the switch **42** of the pH reader **40** is activated and the sensor **56** is activated to measure the blood pH and the pH reader provides a numeric pH value of the blood, which is indicative of the pH level of the vasculature. FIG. 6 shows a pH reading of 6.4 by way of example. Note the guidewire **50** can be inserted utilizing known methods, e.g., through a femoral approach or a brachial approach, and advanced through the vascular system to the desired treatment site, e.g. the cerebral artery. In one method, first an introducer is placed in the femoral artery, and a large guidewire and guide catheter is advanced to the carotid artery. The large guidewire is removed, and replaced with a microcatheter **70** and a smaller dimensioned guidewire **50** of the present invention which contains sensor **56**. The catheter tip **71** (containing marker band **79** for imaging) of catheter **70** and guidewire tip **51** are advanced past the blood clot C (see e.g., FIG. 8A). The sensor **56** measures the pH and transmits the measurement through the wires extending in guidewire **50** back to the cable **83** which in turn transmits it to the reader **40**. As noted above, the closed system advantageously enables the user to determine the vasculature condition by measuring the blood pH rather than the pH of the vasculature (or surrounding tissue) itself. Proper treatment approaches for the treating the blood clot can then be better selected. That is, the physician can determine whether removal of the clot would be too traumatic to the vessel and risk hemorrhaging. The physician can also determine the safe restoration of blood flow and control such blood flow in accordance with the condition of the vessel. Note the different parameters described above are applicable to this embodiment (sensor on the guidewire) as well.

Note the sensors are shown at the distalmost tip of the catheter (FIGS. 1-5) or guidewire (FIGS. 6-8B) but alternatively can be spaced proximal of the distalmost tip such as the sensor **56a** of guidewire **50a** of FIG. 8C.

The pH sensors can be used in other applications such as in cases of gangrene or tissue dying for some other reason to intravascularly assess the vasculature or health of the tissue.

In an alternate embodiment, the oxygen level of the blood can be measured which is indicative of the oxygen and thus the health of the vasculature due to the closed or substantially system closed system resulting from the blood clot. The system would be the same as with the above described systems, except one or more oxygen sensors (rather than pH sensors) would be provided on the catheter and/or the guidewire and connected to an oxygen reader (meter) such as shown in FIG. 2B. The oxygen reader provides an indicator of the oxygen level, by providing for example a numeric value, or other indicator, to indicate a range of low to high oxygen level measurements. The sensors can be

positioned on the catheter or guidewire in the similar manners of the pH sensors disclosed herein.

FIGS. 15-23 illustrate alternate embodiments of the flexible elongated device which supports or carries the sensor. The flexible elongated device includes a hypotube dimensioned for insertion through cerebral arteries or other small vessels. The sensor in these embodiments is carried distal of the hypotube to minimize the outer diameter of the device. Further, radiopaque markers or indicators are provided to identify the sensor location. Various embodiments are disclosed which achieve this minimization while still optimizing the balance between flexibility for navigating the tortuous vasculature and rigidity for pushability/directability through the vasculature to the target site.

Turning first to the embodiment of FIGS. 15-20, the flexible elongated device is designated generally by reference numeral 400 and includes a tubular portion 402 in the form of a hypotube. Tubular portion (hypotube) 402 has a distal region 404, a proximal region 406 and an intermediate region 408 (note the broken lines in FIG. 15). A lumen 410 extends through the tubular portion 402 to receive the wires 413 from the sensor 412. In some embodiments, the proximal region 406 of the hypotube 402 is superelastic, the distal end 404 is non-superelastic and the intermediate region 408 forms a transition region between regions 404 and 406. That is, the proximal region 406 can be austenitic and the distal region 404 can be martensitic. The superelastic material is preferably Nitinol, with a transition temperature greater than body temperature, although other materials are also contemplated. Thus, in this embodiment, the proximal region 406 is austenitic to provide a harder region and the distal region 404 is martensitic to provide a softer region that is shapeable and trackable. In the embodiment shown, the tubular portion 402 does not have a taper but relies instead on the changing properties along its length to achieve trackability. However, in alternate embodiments, the tubular portion 402 can have a tapered distal region to increase flexibility at the distal region.

As shown in FIGS. 15 and 16, the tubular portion 402 has a stepped down transition or transition zone 414 to transition from a larger diameter at the intermediate and proximal regions 408, 406, respectively, to a smaller diameter region 405 in the distal region 404 distal of the transition 414. In some embodiments, by way of example, the intermediate and proximal regions 408, 406, which are proximal of the transition 414, have an outer diameter of about 0.018 inches and the distal region 404 distal of the transition 414 has an outer diameter of about 0.014 inches. Other dimensions are also contemplated. In addition, in alternate embodiments, the hypotube can be formed of multiple diameters. The smaller diameter region 405 can be formed by cutting out a portion of the hypotube 402, by swaging, grinding or other known methods. Note for ease of manufacture, in some embodiments, it is contemplated that the proximal region 406 can be a standard size and the reduced diameter distal region 405 can be of varying sizes to accommodate different clinical applications. That is, in these embodiments, variable sized hypotubes can be provided, with each having a different diameter distal region but the same size diameter proximal region.

Positioned over the reduced diameter region 405 is a coil 420. The reduced diameter 405 and coil 420 can be of various lengths but in one embodiment by way of example they are about 3 cm long, with the hypotube 402 having an overall length of about 165 cm. Other dimensions are also contemplated. When the coil 420 is seated over the reduced diameter distal region 405, it increases the diameter of the

tubular portion 402, preferably to an extent such that the outer diameter of the distal region 404 is substantially equal to the outer diameter of the proximal region 406 to provide a substantially uniform outer diameter of the elongated device 400 for a smooth transition. The coil 420 is preferably composed of a radiopaque material such as platinum. As shown, the coil preferably extends from the transition zone 414 to the distalmost tip 409 of hypotube 402.

A marker band 422 is attached to the tubular portion 402. One method of attachment is securement of proximally extending tab 423 of marker band 422 (FIG. 16) within slot 407 of tubular portion 402 where it is then soldered or welded. The tab and slot arrangement help orient the marker band. Note, the tab, shown extending linearly, can have an upward bend to help maintain its position and orientation with respect to the tubular portion. Other methods of attachment are also contemplated to attach marker band 422 so it extends distally of the distalmost tip 409 of the tubular portion 402. Positioned within marker band 422 is a sensor 412. Thus, the marker band 422 and sensor 412 are positioned distal of the coil 420 and tubular portion 402. Sensor 412 is supported (carried) within marker band 422 by epoxy, a tight fit, silicone or other known methods. The sensor 412 in some embodiments can be in block form having height, width and length dimensions by way of example of between about 0.007 inches and about 0.008 inches, although other dimensions are also contemplated to fit within the internal diameter of the marker band 422. The marker band 422 preferably has a thin wall which is thinner than the wall of the tubular portion 402 and in some embodiments by way of example is between about 0.001 inches and about 0.002 inches while the wall of the tubular portion is between about 0.002 inches and about 0.004 inches. By placing the sensor 412 within the marker band 422 as in this embodiment, there is more room for sensor placement not only because the marker band 422 has a larger outer diameter and larger inner diameter than the reduced diameter distal region 405 of hypotube 402, but the marker band 422 has a thinner wall than the wall of the hypotube 402. This results in a larger internal diameter than the tubular portion 412. Stated another way, the marker band 422 and tubular portion 402 preferably have a substantially equal outer diameter except for the reduced diameter region, where the marker band has a substantially equal diameter to the coil 420 positioned over the distal region of the tubular portion 402. This provides a smooth outer region for insertion though the vasculature. (Note the proximal end of the marker band 422 can abut the distal end of the coil 420). Since the tubular portion 402 should have sufficient rigidity for pushability, its wall should have a sufficient thickness to provide such structural rigidity. Such wall thickness reduces the inner diameter of the tubular portion 402, thus leaving less room for the sensor. The marker band 422, placed at the distal tip of the device 400, does not need to have such rigidity so it can be provided with a thinner wall to thereby leave more internal space for a sensor. Thus, by placement within the marker band, a larger sensor can be accommodated. Additionally, the radiopacity of the marker band 422 provides visibility (e.g., under X-ray fluoroscopy) to inform the clinician of the location of the sensor within the body lumen since the sensor 412 in these embodiments is located within the marker band 422. Note in alternate embodiments, the sensor need not be placed within the marker band, but, for example, if sufficiently small enough, could be placed for example in the tubular portion. Any of the various sensors disclosed herein can be positioned within the marker band.

Wires **413** extend from sensor **412** and through lumen **410** of tubular portion **402** where they attach to a connector for transmitting the measured values to the indicator such as indicator **40** of FIG. **1**. A window or cutout **425** (or **425'**) is formed in the marker band **422** to enable the sensor **412** to communicate with the blood to measure the pH level (or oxygen level) or other parameter as described herein. In the embodiment of FIG. **20A**, a radial cutout extending along an arcuate portion of the circumference is provided, although other shapes, lengths, etc. of the cutout are also contemplated. In an alternate embodiment, an axial (longitudinal) cutout **425'** could be provided in the marker band extending along a partial or entire length of the marker band. (See e.g., FIG. **20B**). As noted above, the marker band **422** is composed of a radiopaque material. One example of a material that can be utilized for the marker band **322** is nitinol, however, other materials can also be utilized. As noted above, by placing the sensor inside the radiopaque marker band, the user can know the location of the sensor **412** by the location of the marker band. A cap **424** such as epoxy material is fitted on the distal end of marker band **422** to cover the distal end and provide a smooth atraumatic closed rounded surface.

In the alternate embodiment of FIG. **21**, the elongated device **430** is identical to device **400** of FIGS. **15-20** except for the additional cutout or depression in the tubular portion (hypotube) **432**. That is, positioned proximal of outer radiopaque coil **434** (identical to coil **420** of FIG. **15**) which is seated over the reduced diameter distal portion of tubular portion **432**, tubular portion **432** has a reduced diameter region **436** to accommodate (mount) a vascular implant, such as a stent or stent retriever for example, for delivery to the target site. The reduced diameter region **436** is shown just proximal of the reduced diameter region of the tubular portion **432** over which the coil **434** is mounted. The device **430** includes a rounded tip **440** and a marker band **438** which carries the sensor therein as in the embodiment of FIG. **15**. Note a soft cover can be placed over the tubular portion **432** for delivery which can be withdrawn once the tubular portion is at the target site to enable expansion of the vascular implant from its collapsed (reduced diameter) configuration for insertion to its expanded configuration for placement when exposed from the confines of the cover. The cover can in some embodiments have a softer tip to increase flexibility of the tip. An additional marker band **442** can be provided on tubular portion **432** in a similar manner as in the embodiment of FIG. **22**. In FIG. **22**, the additional marker band **442** is shown proximal of the reduced diameter region **436'**. This proximal marker band can help provide an indication of the vascular implant location. In all other respects, the elongated device **430'** of FIG. **22** is identical to device **430** of FIG. **21** and corresponding parts/components, e.g., hypotube **432'**, coil **434'**, distal marker band **438'** (with a sensor positioned therein) and tip **440'**, have been given "prime" designations for ease of identification.

In the alternate embodiment of FIG. **23**, flexible elongated device **443** has a tubular portion **444** which supports a distal radiopaque coil **448** and a proximal radiopaque coil **445**. A region **450** of the tubular portion **444** between coils **445** and **448** is exposed. Supported (carried) within the region **450** is a sensor. The region **450** has a cutout or window **452** like cutout **425** to enable communication between the sensor and the blood to measure the aforescribed parameters in the manner described above. The clinician is informed of the location of the sensor since it is between the two radiopaque coils **445**, **448**. The device has a rounded tip or cap **454** similar to tip or cap **424** of the embodiment of FIG. **15**.

The use of the devices **400**, **430**, **430'** and **443** is the same as described herein to measure the pH of the blood to determine the condition of the vessel, with the pH reader providing an indication of the measured pH.

Note the devices **400**, **430**, **430'** can also be used for carrying a density sensor within the marker band (or adjacent the marker band as in device **443**) such as the density sensors described above. They can further be used for the aforescribed oxygen sensors. Additionally, temperature sensors can be carried by the device. Thus, for example, the density sensor can be positioned within the marker band to provide the advantages described above. Wires, a manometric tube, etc. extend within the tubular portion for connection to the reader as described above.

In an alternate embodiment, the sensor, e.g., chip, is encased in a polymeric case rather than in a radiopaque marker band and is injection molded around the tip of the tubular portion to extend distally thereof. Thus, like the marker band **422**, the case (and sensor) would extend distal of the tubular portion providing more space for the sensor therein. The case could be injection molded around the hypotube or around the coil and hypotube over which the coil is positioned. A radiopaque element could be added to the polymeric case for radiopacity.

FIGS. **14A-14D** illustrate one method of use of the present invention illustratively showing the guidewire system of FIG. **6B**. In this system, the health of the vasculature is assessed by measurement of the pH level of the blood downstream of the clot so that a) a determination can be made as to how the blood clot can be treated, including whether the blood clot should even be removed; and b) a determination can be made as to how blood flow should be restored.

FIG. **14A** shows a conventional introducer catheter **300** inserted through the femoral artery to provide access to the vascular system. A conventional guide catheter **302** is inserted through the introducer catheter **300** and advanced through the vascular system to or adjacent the targeted cerebral artery, e.g., advanced to the neck region of the patient. The guidewire of the present invention, such as guidewire **50**, is inserted through the guide catheter **302** and advanced adjacent the blood clot C as shown in FIG. **14B**. (Note the coupler and reader are not shown in FIGS. **14A-14D**) The guidewire **50** is then advanced past the clot C to a position downstream of the blood clot (occlusion). The pH level of the blood downstream of the blood clot is measured by the pH sensor as described above (or alternatively by the oxygen sensor if an oxygen sensor is utilized) and the reader provides a readout of the pH level. Based on this reading, the user is made aware of the pH level of the vessel downstream of the clot C, and thus the health of the vessel. This enables the user to determine, e.g., based on comparison to a predetermined pH level, if intravenous thrombolytic therapy, e.g., injection of drugs to break up the clot, aspiration or mechanical thrombectomy to grasp and remove the clot, is the better treatment method, or whether removal of the blood clot is too high risk and therefore should not be removed. The reading also enables the user to determine the effect of blood flow on the vessel downstream of the clot once the blood clot is removed and blood flow is restored.

FIG. **14C** illustrates the next step of inserting a microcatheter **304** over the guidewire **50**. The microcatheter selected is based on the health of the vasculature. For example, in FIG. **14C**, a mechanical treatment is selected and the microcatheter **304** having a mechanical thrombectomy device **306** such as a stent-like device is inserted over

the guidewire 50. Note the mechanical thrombectomy device 306 has an expandable stent structure which when expands captures clot which is removed as the stent is collapsed and withdrawn with the catheter. However, other mechanical thrombectomy devices can be utilized such as motor controlled rotational wires. In the method shown in FIG. 14C, the vasculature has been determined to have a low pH level, for example, below a pH level of 7, or another predetermined level, so the microcatheter selected also includes structure to provide slow reperfusion post clot treatment. More specifically, microcatheter 304 has an inflation lumen 308 and an inflatable balloon 310 positioned at a distal end. The microcatheter 304 is advanced distal of the blood clot C and the balloon 310 is inflated via inflation fluid through lumen 308 prior to, during or after removal of the clot C as shown in FIG. 14C. In this manner, as the device 306 removes the clot C, the blood flow is controlled, i.e., full blood flow is not immediately restored. The balloon 310 can be slowly and partially deflated to gradually restore full blood flow as the pH level rises as determined by the continued measurement of the pH level of the blood by the sensor of the guidewire 50. With the pH level returned to a safe level, the balloon can be deflated and the microcatheter 304 removed with blood flow fully restored. Note the guidewire 50 can be removed from within microcatheter 304 prior to use of the device 306 to remove the blood clot so as not to interfere with the device 306. It can periodically be reinserted within microcatheter 304 to measure the pH level of the blood. In alternate embodiments, the guidewire 50 can be left in place within the microcatheter so the sensor at the distal end can continuously or periodically measure the blood pH. As can be appreciated, in this method, neither a guidewire nor catheter exchange is necessary. In some alternate embodiments, the microcatheter can include the pH sensor so the guidewire could be removed and need not be reinserted for later measurement. As can be appreciated, in this method neither a guidewire nor catheter exchange are necessary.

Although the balloon of FIG. 14C is shown distal of the blood clot, it is also contemplated that the balloon can be positioned on the microcatheter proximal of the blood clot as in FIG. 14E. As shown, a balloon 311 can be positioned on microcatheter 304' in addition to or in lieu of balloon 310 to control restoration of blood flow. Alternatively, the guide catheter can have a balloon at a distal end which is inflatable at a position proximal of the blood clot (FIG. 14F). As shown, balloon 303 is positioned on guide catheter 302' and can be provided in addition to or in lieu of balloon 310 (and/or balloon 311). The balloons of these embodiments would block or reduce blood flow until restoration of full blood flow is desired. Thus, such balloons can be expanded proximal and/or distal of the blood clot to control blood flow.

In the alternate embodiment of FIG. 14D, the method of FIGS. 14A-14C is the same except a microcatheter 312 different than microcatheter 306 is utilized when a determination is made, based on a pH level below a predetermined level, e.g., below a pH level of 7, or another predetermined level such as the levels discussed above, that slow reperfusion during or after blood clot treatment (removal) is warranted. Microcatheter 312 has a lumen 314 for injection of cryogenic fluid. Injection of this cooling fluid cools slows the blood flow to provide an alternate method of slowly restoring blood flow post clot removal. The guidewire 50 can be removed from within microcatheter 312 prior to use if desired and periodically reinserted if desired, or alterna-

tively left in place as discussed above. The microcatheter can in an alternate embodiment include a pH sensor.

Note if an interventional therapy treatment is utilized, the catheter to inject the drugs for blood clot removal can have a separate inflation lumen and an inflatable balloon to function to regulate blood flow in the same manner as balloon 310 of microcatheter 304 or can have a lumen, either the same or different from the lumen to inject the drugs, to inject the cooling fluid to slowly restore blood flow in the same manner as microcatheter 312.

Note a comparison is made of the pH level to a predetermined level to determine how to treat the clot. A comparison is also made of the pH level to a predetermined level to determine if slow reperfusion is warranted. These predetermined levels can be the same or different levels. Examples of such predetermined levels are discussed above, as well as other levels, are fully applicable to these embodiments of FIGS. 14A-14F as well.

Further note that the microcatheter can be inserted over the guidewire before or after pH level is measured. Also, in alternate embodiments the guide catheter can be provided with a mechanical thrombectomy device to remove the clot and/or a balloon or cooling fluid lumen so that a separate catheter, e.g. microcatheter 312, need not be utilized.

Also note that microcatheters 304 and 312 are examples of catheters that can be utilized to slow reperfusion, it being understood, that other catheters with other structure to slow reperfusion are contemplated. Additionally, use of the balloon or cooling fluid disclosed herein can be used on catheters other than catheters with the structure of catheters 304 and 312.

In the embodiment of FIG. 1 where a catheter rather than a guidewire is utilized to measure pH levels of blood, a microcatheter with a balloon or lumen for injection of cryogenic fluid can utilized to slowly restore blood flow in the manner described above.

Note the aforescribed sensors thereby provide a means for measuring the blood pH which can be utilized to determine the health of the vasculature, the reader provides a means for indicating the sensed pH, the microcatheter provides a means for removing the clot and the inflatable balloon or cryogenic fluid provides a means for controlling the rate of blood flow after clot removal.

Note the systems described above assess the blood distal of the blood clot, however, it is also contemplated that assessment of the blood via pH measurement can be performed adjacent the blood clot but proximal to the blood clot in the aforescribed closed or substantially closed system. Such reading proximal the blood clot can also provide a reading of the vessel vitality adjacent the clot and therefore distal the clot.

Note the aforescribed systems can alternatively measure oxygen level of the blood rather than pH level as discussed above to determine the health of the vasculature and determine treatment as in FIGS. 14A-14F.

The systems are described herein mainly for use with treating blood clots. However, any of the systems disclosed herein can also be used in other clinical applications. For example, one alternate application is to assess the condition of an organ, e.g., a transplanted organ such as a kidney, by measuring the pH of blood within the vasculature of the organ to assess the condition of the organ. That is, an assessment of pH level in a vessel within the organ to assess vessel vitality will provide an indication of the pH level of the organ to determine the vitality of the organ and whether steps need to be taken to address the organ going bad or potentially not functioning properly.

Clot Determination and Clot Removal Tracking

As noted above, the present disclosure provides a system to identify a parameter such as the composition of a blood clot in a vessel which will enable the physician to scientifically determine the clot makeup and determine the best course of treatment from the available tool sets. This can be achieved in accordance with one embodiment using ultrasound. Such ultrasound system can also be used during the procedure and/or after the procedure to measure clot density so the clinician can determine if the blood clot has effectively been reduced or sufficiently removed from the vessel.

In the embodiment utilizing ultrasonic waves, the density of the clot can be estimated, in vivo, by determining the time it takes for an ultrasonic sound wave to “bounce” back from the clot. The longer the signal takes to return, the less dense the clot is. That is, an ultrasound signal will return more quickly when interacting with a denser substrate. The average densities of traditional “soft” clot and the denser fibrin clot is determined to provide predetermined parameters, and then the system of the present disclosure compares the signal generated by the ultrasonic wave to these parameters to inform the physician of the type of clot. Thus, the system utilizes a logic circuit to determine the makeup of the clot quickly, efficiently and effectively. By way of example, a soft clot can be assigned a numeral **1** and a hard clot assigned a numeral **10**, and the clot density measured to assign a value within this range so the physician would first be informed of the type of clot before taking treatment steps, such as removal of the clot. In other words, the measured average densities of both soft clot and fibrin will provide a “baseline” incorporated into the logic-circuit which will determine, in vivo during the surgical procedure, which clot type is present within the vessel. Other numeric values or indicators are also contemplated to indicate varying densities. Thus, the predetermined baseline and the assessment in accordance with this baseline provide a means to provide a density value for the clinician thereby providing a convenient method for the physician to assess the blood clot.

In the system, to generate and provide a digital or analog readout of these ultrasound signals a piezoelectric signal transducer can be used. Piezoelectric materials are crystalline structures which undergo a mechanical deformation when a certain voltage is applied to the crystal. This property is used in conjunction with an applied AC voltage applied to the crystal. As the AC voltage is applied to the piezoelectric material it will deform and generate a sound wave. Likewise, when a mechanical load is placed on the piezoelectric crystal a small voltage is generated. This property is used to convert an ultrasonic signal into a measurable voltage. The piezoelectric crystal has a specific voltage/frequency relationship which can be used to convert between the two.

Because of these unique properties, the same piezoelectric transducer which generates an ultrasonic signal can also be used to receive the reflected signal returning from a substrate. Utilizing these properties the ΔT (change in time) can be determined between the sent signal and the received signal by having predetermined the average ΔT for both normal and fibrin clots; the designed logic circuit will be able to determine which clot is present.

This ultrasonic signal is sent from within the vasculature to ensure that interference from cranial tissues, muscle, bone, etc. do not affect measurements. The size and shape of the piezoelectric crystal will determine the distance at which the measurement can be best made.

Turning now to the system of FIGS. 9A-12B, a system for determining the type of clot is illustrated, with FIG. 9A illustrating an embodiment where the density sensor (utiliz-

ing ultrasound as described above) is on a catheter and FIG. 11A illustrating an embodiment where the density sensor (utilizing ultrasound) is on a guidewire. It is also contemplated that a density sensor can be positioned on the catheter and on the guidewire, and it is also contemplated that one or more density sensors can be positioned on the catheter and one or more density sensors can be positioned on the guidewire. This enables more than one region of the clot to be measured which could be beneficial in large clots.

Turning more specifically to the system of FIGS. 9A, 9B and 10, catheter **110** has a proximal portion **112** and a distal portion **114**. The catheter tube **116** is sufficiently flexible to navigate the small vessels while having some rigidity to enable it to be directed around the curves of the vasculature. An RHV **120** is attached to the catheter hub **122** and includes a side arm **124** for fluid injection and/or aspiration. Coupler **130** is attached to the catheter **110**, and is connected to cable **134** which is connected to density reader (meter) **140**. In one embodiment, the coupler **130** can be the same as coupler **30** of the embodiment of FIG. 1 and can be u-shaped with an opening between the legs of the “u” dimensioned to frictionally clamp onto the outer wall of the catheter **110**. That is, the coupler can be in the form of a U-shaped clip with the radius of the U smaller than that of the outer wall of the catheter so it flexes outwardly when placed over the strain relief of the catheter and then is frictionally retained on the catheter. In another embodiment, a second connector half is placed opposite the connector to form a 360 degree clip or clamp surrounding the outer wall of the catheter to retain the connector (coupler) on the catheter **110**. Other methods of attachment are also contemplated such as magnetic attachments. A cable **134** is connected to the coupler at one end **135** and connected at the opposing end **136** to density reader **140**. As shown, the coupler **130** is attached to the region of catheter **110** just distal of hub **122**, although other locations are also contemplated.

The density sensor **126** is positioned at the distal portion **114** of the catheter **110**, at the distalmost tip **115** and is electrically coupled to cable **134** via a pair of wires (not shown) extending from the sensor **126** to the coupler **130** and/or cable **134**. The wires can be embedded in a wall of the catheter **110** or alternatively extend through a lumen in the catheter **110**. The sensor **126** in the illustrated embodiment is at the distalmost tip but alternatively could be spaced from the distalmost end so the catheter tip can extend past the clot during use while the sensor is positioned within the clot. The sensor can be positioned on an outer wall of the catheter **110**, extending circumferentially around 360 degrees. The sensor can also be positioned inside the catheter **110**, either internal of the inner catheter wall or alternatively embedded in the wall of the catheter. The sensor can alternatively be positioned within a marker band on the catheter, with a portion of the marker band removed (a cutout formed) to expose the sensor as in FIG. 20A for example. The sensor can be positioned within the marker band in the same manner as the sensor in FIGS. 15-22. Wires (not shown) connect the sensor to the coupler **130** and/or cable **134**.

The density reader **140** provides an indicator device and contains an on off switch **142**. A reading **144** provides a visual indication as a numeric value representative of a comparative density as explained above. FIG. 10 shows a density reading of “5” by way of example, indicating a clot density midway between the outer soft clot and outer hard clot range. As noted above, these numerical values are assigned in accordance with predetermined density averages assigned a representative numeric value within a range of values. Connector (coupler **120**) is wired to the reader **140**

which provides a reading of the clot type based on the signal received from the sensor **126** in response to the ultrasonic signal caused by the ultrasonic waves applied to the clot. Thus, the reader provides a means to display the density, the density displayed in a convenient display as the system processes the time change in sent and received signals to assess density, conducts via an algorithm, a comparative analysis to predetermined density value (e.g., a value of zero), or to predetermined density ranges and then converts it to a numeric value representative of the density within a given range of densities. Thus, the clinician does not need to conduct additional analysis to interpret the measured clot density but can simply rely on the assigned numerical value. This is illustrated in the flow chart of FIG. **24A**.

In use, the catheter **110** can be inserted utilizing known methods, e.g., through a femoral approach or a brachial approach, and advanced through the vascular system to the desired treatment site, e.g., the cerebral artery A. The catheter tip **115** is advanced past the blood clot C (see e.g., FIG. **9B**) so the sensor **126** is located within the blood clot. The sensor **126** is activated, using ultrasonic waves to measure density, with the density reader providing a visual density indication so the user can decide the optimal way to treat the clot.

FIG. **11A** illustrates an alternate embodiment for measuring density utilizing a sensor on a guidewire instead of the catheter as in FIG. **9A**. The guidewire provides a reduced profile measurement system. It also provides a more flexible system to navigate tortuous vessels. Also, by being smaller it can be inserted more distal within the cerebral vasculature. It could also be more steerable and could traverse the clot easier. In some embodiments, by way of example, the outer diameter of the guidewire can be between about 0.010" and about 0.032", although other ranges of sizes are also contemplated. In some embodiments, the outer diameter can be about 0.014".

Guidewire **150** has a proximal portion **152** and a distal portion **154**. The guidewire **150** is sufficiently rigid to navigate the small vessels while having some rigidity to enable it to be directed around the curves of the vasculature. In one embodiment, the guidewire is hollow to form a lumen and the wires run through the lumen from the sensor to the connector. The wires are preferably insulated. In another embodiment, the guidewire is a solid core and a polymeric jacket contains the insulated wires on an outer surface of the guidewire. The guidewire is illustrated within a lumen of a catheter **170** having a RHV **174** attached to the proximal end. The RHV **174** is attached to the hub **172** of catheter **170** and includes a side arm **175** for injection and/or aspiration. Coupler **180** is attached to the guidewire **150**, and is connected to cable **183** which is connected to density reader **140**. The density reader **140** can be the same and function in the same manner as in the embodiment of FIG. **10** described above. In one embodiment, the coupler is the same as coupler **80** of FIG. **7** and is u-shaped with an opening in the "u" dimensioned to frictionally clamp onto the wall of the guidewire **150**. A two part connector (coupler) as described above can also be utilized. Other methods of attachment are also contemplated such as magnetic attachments. Cable **183** is connected to the coupler **180** at one end **185** and connected at the opposing end **186** to meter (reader) **140**.

Density sensor **156** is positioned at a distal end of the guidewire **150**, either at the distalmost tip or spaced from the distalmost tip as shown in FIG. **11B**, and is electrically coupled to coupler **180** and/or cable **183** via a pair of wires (not shown) extending from the sensor **156** to the coupler/cable. The wires can be embedded in a wall of the guidewire

150 or alternatively the guidewire can have a lumen or channel through which the wires extend. In the embodiment of FIGS. **11A** and **11B**, the sensor **156** is positioned on an outer wall of the guidewire **150**, extending circumferentially around 360 degrees. The sensor can also be incorporated into a marker band at the tip of the guidewire **150**. In an alternate embodiment, the sensor can be positioned inside the guidewire **150**, either internal of the inner wall of the guidewire in the same manner as in the embodiment of FIG. **8B**, or alternatively embedded in the wall of the guidewire. In some embodiments, the guidewire has a marker band with a cut or removed portion to expose the sensor mounted within the marker band as in FIG. **20A** for example. In some embodiments by way of example, the marker band can have an outer diameter of about 0.014" and an inner diameter of about 0.012". Other dimensions are also contemplated. The catheter **170** through which the guidewire extends can have a marker band for imaging. The sensor can be positioned within the marker band in the same manner as the sensor in FIGS. **15-22**. Note in FIG. **11A**, the guidewire **150** is positioned with the sensor in the clot C and the catheter **170** is positioned in a cerebral artery A proximal of clot C.

In use, the density sensor **156** is activated to selectively measure the density of the blood clot and with switch **142** turned on, density indication is provided. The density measurement, comparative analysis, conversion to numeric value, etc. is the same as described above (see also FIG. **24A**). Note the guidewire **150** can be inserted utilizing known methods, e.g., through a femoral approach or a brachial approach, and advanced through the vascular system to the desired treatment site, e.g. the cerebral artery. In a preferred method, first an introducer is placed in the femoral artery, and a large guidewire and guide catheter are advanced to the carotid artery. The large guidewire is removed, and replaced with a microcatheter **170** and a smaller dimensioned guidewire **150** of the present invention which contains sensor **156**. The catheter tip **171** is advanced past the blood clot C. The guidewire **150** is positioned in the clot and in some embodiments the catheter **170** is withdrawn proximally to expose the sensor **156** within the clot C to measure the density of the clot (in other embodiments, the sensor is exposed so the catheter does not need to be withdrawn). The sensor **156** transmits the measurement through the wires extending in guidewire **150** back to the cable **183** which in turn transmits it to the reader **140**. Proper treatment approaches for the treating the blood clot can then be better selected. That is, the reader **140** is used to indicate density measurement so the physician can determine the optimal way to treat the clot. For example, if density measurement determines a soft clot, aspiration can be utilized (mechanical devices are generally not designed for soft clot); if a hard clot, aspiration might not be effective to remove the clot so a mechanical removal device can be utilized. Without density determination, the clinician in certain instances might need to try several different devices to effect satisfactory clot removal which could be more expensive and is time consuming due to withdrawal and insertion of different devices. In short, the pre-treatment density determination provides the clinician with additional knowledge to optimize and increase the efficiency of clot removal.

The system for measuring density to determine approaches to treating the clot, using either the aforementioned catheter system or guidewire system, can also be utilized additionally or alternatively, to determine the density of the clot after the clot removal procedure has been selected and commenced. Clot removal can be performed for

example by a thrombectomy device which has a mechanical component to break up the clot as it is rotated, by an aspiration device which aspirates the clot, or by other methods. During the procedure, as the clot is removed, the density of the clot will decrease. In addition, the length of the clot will decrease as the clot is removed. By taking measurements of the clot during the procedure, an indication can be provided to the clinician (user or physician) of the status of clot removal. Further, either alternatively or in addition, the measurement can be used at the end of the blood clot removal procedure. That is, if the clinician believes the clot has been sufficiently removed, before ending the procedure, the density measuring system can be utilized to determine the clot density and thus confirm the clot has been effectively removed.

More specifically, at the start of the procedure, the density of the clot can be determined by ultrasound waves as described herein to provide an initial value. In one embodiment, this initial value can be the value described above which provides a numerical value for comparison to a predetermined baseline. At any time during the procedure, the user can activate the system to generate the ultrasound waves to measure the density of the clot by measuring the transmitted and received signals as described above. This measurement can be compared to the initial value to ensure the density is decreasing. In certain embodiments, once a certain reduced density level is reached, the clinician is informed that a sufficient portion of the clot has been removed. Such density measuring system avoids the need for the clinician to inject contrast which can in certain instances have the adverse effect of re-compacting the clot.

In some embodiments, an initial density value determined at the start of the procedure (represented by "X1" in FIG. 25) can be a value representative of the actual density of the clot. Optionally, another initial value (represented by "Y1" in FIG. 25) can also be representative of the length of the clot. In this embodiment, these two initial values can be recorded and/or indicated on the density reader of FIG. 25, preferably displayed in a window(s) 145 of reader 140' separate from the comparative density numeric value 144', e.g. "5". When during the procedure, the clinician desires to know the clot density and/or length (since a reduction in the length is indicative of the clot being reduced), these measurements can be taken and indicated on reader 140', represented by X2 and Y2, respectively, for comparison to the respective initial values X1, Y1. As the new values (X2 . . . Xn, Y2 . . . Yn) decrease relative to the initial values, the clinician is informed that the clot is being reduced, and after a period of time, indicate that the clot has been effectively removed.

A method of using the system to determine a state of blood clot removal (i.e., tracking removal) from a vessel of a patient, with reference to the flow chart of FIG. 24B, can encompass the steps of inserting an elongated flexible member, e.g., a guidewire or a catheter, having a density measuring component, through vasculature of the patient and adjacent the blood clot, measuring a density of the blood clot to obtain a first value (the first value representative of a density measurement pre-treatment), and to determine a blood clot removal approach, inserting a clot removal device, e.g., a mechanical thrombectomy device or an aspiration device, to remove the blood clot, and after commencement of treatment of the blood clot (by the clot removal device) measuring the density of the blood clot to obtain a second (subsequent) value so that the second value can be compared to the first value to inform the clinician of the extent of removal of the blood clot from the vessel. Obtaining the second value can occur during the treatment or when

the clinician believes the clot has been sufficiently removed, e.g., by viewing the collection bag, and therefore believes that treatment can be terminated. Measurements, if desired, can be repeatedly taken during the procedure, i.e., as portions of the clot are removed, to provide real time indication (assessment) of the blood clot removal. As noted above, these values can be displayed on a display to provide a visual indication and/or comparative analysis of the current status of the blood clot. Once the comparison of the subsequent measurement to the initial measurement indicates the blood clot has effectively been removed, the procedure can be terminated and the clot removal device and elongated flexible member with sensor removed from the body.

To further assist the clot treatment determination, the system and method can optionally include the steps of a) determining a length of the blood clot prior to commencement of the procedure to remove the blood clot and b) determining the length of the blood clot after commencement of the procedure to remove the blood clot to determine a decrease in length of the blood clot. Such length determination can be made repeatedly if desired during removal of portions of the blood clot and/or when the clinician believes the clot has been removed.

As noted above, this system and method can be utilized in conjunction with a catheter or guidewire having a sensor for measuring pH level (or oxygen or other parameter) and an indicator to the user of such level of the blood to enable the user to determine a pH level (or oxygen or other parameter) of the vessel downstream of the blood clot utilizing the systems described herein for a) selection of a treatment method to remove the blood clot, including non-removal; and/or b) a determination whether slow reperfusion during and/or after removal of the blood clot is warranted.

Note that the flexible devices 400, 430, 430' can be used in the same manner as described herein to measure the density of the clot to determine the condition of the vessel using a density sensor positioned within the marker band (or adjacent as in device 443), with the density reader providing an indication of the density.

40 Combination of Systems

It is contemplated that the system for determining clot density (or other clot parameter) and the system for measuring the blood pH (or other blood parameter such as oxygen) can be used together. In such system, both the density sensor and pH sensor (or oxygen sensor) along with a density and pH (or oxygen) reader are provided. Such system is shown in the embodiment of FIGS. 12A-13. The system can also include measuring density to track blood clot removal as described above and the reader described below can be modified to indicate such measurement(s) as in reader 140' of FIG. 16.

Catheter 210 has a proximal portion 212 and a distal portion 214. The catheter tube 216 is sufficiently flexible to navigate the small vessels while having some rigidity to enable it to be directed around the curves of the vasculature. An RHV 220 is attached to the catheter hub 222 and includes a side arm 224 for fluid injection and/or aspiration. Coupler 230 is attached to the catheter 210, and is connected to cable 234 which is connected to pH reader (meter) 241 of reader 240. Reader 240 provides both a pH reading and a density reading. Although shown as a single reader (meter), it is also contemplated that separate meters, such as in FIGS. 2 and 10 could be provided. In one embodiment, the coupler 230 is identical to the embodiment of FIG. 4, being U-shaped with an opening in the "u" dimensioned to frictionally clamp onto the outer wall of the catheter 210. Alternatively, a second connector (coupler) half as described above can be utilized.

Other methods of attachment such as magnetic attachment are also contemplated. Cable **234** is connected to the coupler **230** at one end **235** and connected at the opposing end **236** to reader **241**. As shown, the coupler **230** is attached to the region of catheter **210** just distal of hub **222**, although other locations are also contemplated.

The pH sensor **226**, identical to the sensor of FIG. 1, is positioned at the distal portion **214** of the catheter **210** and is electrically coupled to cable **234** via a pair of wires (not shown) extending from the sensor **226** to the coupler **230** and/or cable **234**. The wires can be embedded in a wall of the catheter **210** or alternatively extend through a lumen in the catheter **210**. In the embodiment of FIG. 12A, the sensor is positioned on an outer wall of the catheter **210**, extending circumferentially around 360 degrees in an identical manner as shown in FIG. 3A. The sensor can also be incorporated into or positioned within a marker band at the tip of the catheter **210** in the same manner as in FIGS. 16-22. In the alternate embodiment, the sensor can be positioned inside the catheter **210** (similar to sensor **26'** of FIG. 3B), either internal of the inner catheter wall or alternatively embedded in the wall of the catheter. The pH sensor can be positioned at the distalmost tip as shown or alternatively spaced proximally of the distalmost tip. Wires connect the sensor **236** to the coupler **230** and/or cable **224**.

The pH reader **241** contains an on off switch **248** to selectively provide a readout of the measured pH. A reading **244** provides a visual indication, as a numeric value, of the measured pH of the blood for the user to determine the pH of the vasculature. A pH of 6.9 is shown by way of example.

Guidewire **250** has a proximal portion **252** and a distal portion **254**. The guidewire **250** is sufficiently rigid to navigate the small vessels while having some rigidity to enable it to be directed around the curves of the vasculature. The guidewire **250** is illustrated within a lumen of catheter **210**. Coupler **280** is attached to the guidewire **250**, and is connected to cable **283** which is connected to density reader **245** of reader **240**. In one embodiment, the coupler **280** is the same as coupler **80** of FIG. 7 and is u-shaped with opening in the "u" dimensioned to frictionally clamp onto the wall of the guidewire **250**. Alternatively, a second connector (coupler) half as described above can be utilized. Other methods of attachment such as magnetic attachment are also contemplated. Cable **283** is connected to the coupler **280** at one end **285** and connected at the opposing end **286** to reader (meter) **245**.

A density sensor **256**, which is identical to sensor **156** of FIG. 11B, is positioned at a distal portion of the guidewire **250**, spaced proximally of the distalmost tip, and is electrically coupled to coupler **280** and/or cable **283** via a pair of wires (not shown) extending from the sensor. The wires can be embedded in a wall of the guidewire **250** or alternatively the guidewire can have a lumen or channel through which the wires extend. In the embodiment of FIG. 12A, the sensor **256** is positioned on an outer wall of the guidewire **250** in the same manner as sensor **156** of FIG. 11B, extending circumferentially around 360 degrees. The sensor **256** can also be incorporated into a marker band at the tip of the guidewire **250**. In an alternate embodiment, the sensor can be positioned inside the guidewire **250**, either internal of the inner wall of the guidewire in the same manner as shown in FIG. 8B, or alternatively embedded in the wall of the guidewire. The sensor can be positioned within the marker band in the same manner as the sensor in FIGS. 15-22. The catheter **210** through which the guidewire **250** extends can have a marker band. Note in FIG. 12A, the catheter **210** and guidewire **250** are positioned in a cerebral artery A distal of

clot C. In use, the catheter **210** can be withdrawn with respect to the guidewire **250** to expose the density sensor **256** within the clot as shown in FIG. 12B where the density sensor **256** is proximal of the distal tip (in other embodiments, the sensor is exposed so the catheter does not need to be withdrawn). In the embodiment wherein the density sensor **256** is at the distalmost tip, the guidewire **250** would be withdrawn further proximally until the distalmost tip (and sensor) is positioned in the clot.

In the embodiment where the pH sensor is on the guidewire (as in the embodiment of FIG. 6) and the density sensor is on the catheter (as in the embodiment of FIG. 9A), the catheter need not be withdrawn. The density sensor **256** in some embodiments can be positioned proximal of the pH sensor **226** during use since the density sensor is exposed on the outside of the catheter to measure the blood clot parameter and the pH sensor is exposed on the guidewire to measure the blood parameter downstream of the blood clot. In use, the density sensor is activated to measure clot density and switch **247** of the density reader **245** of reader **240** is turned on to provide a visual numeric indication of a relative density. Density can be measured at various times during the procedure to track clot removal as described above. The pH sensor is activated either simultaneously, or at a different time, so pH reader **241** provides a visual numeric indication of blood pH.

It is also contemplated that in some embodiments a pH sensor (or oxygen sensor) and a density sensor can both be positioned on a single guidewire or a single catheter.

Note the guidewire **250** can be inserted utilizing known methods, e.g., through a femoral approach or a brachial approach, and advanced through the vascular system to the desired treatment site, e.g., the cerebral artery. In one method, first an introducer would be placed in the femoral artery, and a large guidewire and guide catheter would be advanced to the carotid artery. The large guidewire is removed, and replaced with a microcatheter **210** which contains a pH (or oxygen) sensor (or alternatively a density sensor) and a smaller dimensioned guidewire **250** of the present invention which contains sensor **256**. The catheter tip **271** is advanced past the blood clot C. The sensor **256** of guidewire **250** is positioned in the clot so the sensor measures the density of the clot and transmits the measurement through the wires extending in guidewire **250** back to the cable **283** which in turn transmits it to the density reader **245** of reader **240**. (In the embodiment where the catheter contains the density sensor, the guidewire can contain the pH (or oxygen) sensor. The pH sensor **226** is positioned distal (downstream) of the blood clot to measure pH of the blood distal of the clot and transmit it via wires to the cable and pH reader **241**. As noted above, the closed (or substantially closed) system advantageously enables the user to determine the vasculature condition by measuring the blood pH rather than the pH of the vasculature (and surrounding tissue) itself. Proper treatment approaches for treating the blood clot (or not treating the clot as discussed above) and/or restoring blood flow can be better selected. The density reading provides information on the blood clot itself which can be utilized to determine blood clot treatment. The reader can also include readings of density after treatment commences so the user can determine the status of blood clot removal. As noted above, an oxygen sensor can be used in the closed or substantially closed system to determine the vasculature condition.

Note that the devices **400**, **430**, **430'** and **443** can be used in the same manner as described herein to measure the pH of the blood to determine the condition of the vessel and to

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measure the density of the clot, with one or both of the sensors within the marker band and the pH reader and density reader providing an indication of such measurements. A temperature sensor to measure temperature of the vasculature could also be provided on the device or within the marker band.

Note the couplers described herein are preferably coupled to the catheter or guidewire prior to their insertion. However, alternatively, coupling can occur subsequent to insertion to facilitate maneuverability to the target site.

While the above description contains many specifics, those specifics should not be construed as limitations on the scope of the disclosure, but merely as exemplifications of preferred embodiments thereof. Those skilled in the art will envision many other possible variations that are within the scope and spirit of the disclosure as defined by the claims appended hereto.

What is claimed:

1. A system for determining a pH level of blood in a vessel of a patient, the system comprising:

a flexible elongated device configured and dimensioned for insertion in the vessel of the patient, the elongated device having a proximal portion, a distal portion and a tubular portion having a lumen formed therein, the elongated device configured for insertion so the distal portion extends past a blood clot for positioning of the distal portion distal of the blood clot;

a marker band, at least a portion of the marker band positioned distally of a distalmost edge of the tubular portion, and exposed from the tubular portion, wherein the marker band has an internal diameter larger than an internal diameter of the tubular portion from which it distally extends;

a sensor for positioning distal of the blood clot, the sensor positioned within the marker band and positioned distally of the distalmost edge of the tubular portion; and

a connector operably connecting the tubular portion to an indicator, the sensor is configured to measure the pH level of blood downstream of the blood clot to thereby determine pH of the vessel downstream of the blood clot to determine the condition of the vessel to assess subsequent treatment of the blood clot, the indicator providing an indication of the pH measured by the sensor.

2. The system of claim 1, wherein the tubular portion comprises a hypotube.

3. The system of claim 2, wherein the hypotube has a martensitic distal region and an austenitic proximal region.

4. The system of claim 1, wherein the tubular portion has a first wall thickness and the marker band has a second wall thickness, the second wall thickness being less than the first wall thickness at a distal portion of the tubular portion so the marker band has the larger internal diameter.

5. The system of claim 4, wherein the first wall thickness is between about 0.002 inches and about 0.004 inches and the second wall thickness is between about 0.001 inches and about 0.002 inches.

6. The system of claim 4, wherein the tubular portion has a first outer diameter and the marker band has a second outer diameter substantially equal to the first outer diameter.

7. The system of claim 1, wherein the marker band has a window to enable communication of the sensor with the blood in the vessel.

8. The system of claim 1, wherein the tubular portion has a first reduced diameter region at a distal region, and a radiopaque coil is positioned on the first reduced diameter region.

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9. The system of claim 8, wherein the tubular portion has a second reduced diameter region formed proximal of the first reduced diameter region to support a vascular implant.

10. The system of claim 8, further comprising a second radiopaque coil positioned on the tubular portion proximal of the first radiopaque coil, and a gap is formed between the first and second coils providing an exposed region having a window, the sensor positioned within the tubular portion and aligned with the window.

11. The system of claim 1, further comprising a second marker band positioned proximal of the first marker band which has the sensor therein.

12. The system of claim 1, wherein the sensor is contained in a microchip and a wire extends through the lumen of the tubular portion.

13. The system of claim 1, further comprising a second sensor for sensing a parameter of the blood clot and a second indicator to indicate the sensed parameter, the second sensor connected to the second indicator and configured to sense a density of the blood clot.

14. The system of claim 13, wherein the second sensor is positioned within the marker band.

15. The system of claim 1, wherein the sensor includes fiber optics transmission.

16. The system of claim 1, wherein the indicator communicating with the sensor is configured to be positioned outside the patient, the indicator indicating the pH level of the blood.

17. A method for determining a pH level of blood downstream of a cerebral blood clot in a cerebral vessel of a patient comprising the steps of:

providing an elongated flexible device having a) a tubular portion, b) a radiopaque marker band exposed from the tubular portion and extending distally from a distalmost edge of the tubular portion, an internal diameter of the marker band is larger than an internal diameter of a distal portion of the tubular portion, and c) a sensor positioned within the internal space of the marker band;

inserting the flexible device through vasculature of the patient and past the cerebral blood clot to a position downstream of the blood clot in the vessel, the marker band indicating to the user the position of the sensor;

sensing a pH level of the blood downstream of the blood clot;

indicating to the user the pH level of the blood to enable the user to determine a pH level of the vessel downstream of the blood clot for subsequent selection of a clot treatment method; and

indicating to the user the position of the sensor due to its placement within the internal space of the marker band.

18. The method of claim 17, further comprising the step of determining a density of the blood clot to determine the clot treatment method.

19. The method of claim 17, further comprising a connector connecting the flexible device to an indicator to indicate the pH level.

20. The method claim 17, wherein the tubular portion has a first wall thickness and the marker band has a second wall thickness, the second wall thickness being less than the first wall thickness at a distal portion of the tubular portion so the marker band has a larger internal diameter than an internal diameter at the distal portion of the tubular portion.